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LITIGATION TECHNICAL SUPPORT AND SERVICES

Rocky Mountain Arsenal

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Boundary Control Systems
Assessment Remedial Investigation
Draft Final Report
(Version 2.2)
Volume I

November 1989
Contract Number DAAK11-84-D-0016
Task Number 25

PREPARED BY

ENVIRONMENTAL SCIENCE & ENGINEERING, INC.

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PREPARED FOR

Office of Program Manager
Rocky Mountain Arsenal Contamination Cleanup

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EXECUTIVE SUMMARY

The primary purpose of the Boundary Control Systems Assessment Remedial Investigation (Task 25) was to collect water quality data upgradient and downgradient of the North Boundary Containment System (NBCS) and Northwest Boundary Containment System (NWBCS) at the Rocky Mountain Arsenal (RMA). This data was used to define the concentration and areal extent of contaminated water reaching the two boundary systems as well as the areal extent of contaminated water remaining downgradient of the systems. Data collected since 1985 by Shell (1987, RIC#87271R01) were used to prepare documents for the assessment of the Irondale Containment System (ICS). No assessment of the ICS is included in this report.

This assessment included the sampling of monitor wells in both the alluvial aquifer and Denver Formation (Fm) during six quarters, from the fourth quarter of Fiscal Year 1986 (FY86) through the first quarter of Fiscal Year 1988 (FY88). It also included an interpretation of water level data for wells in the vicinity of the boundary systems, as well as a detailed geologic and hydrogeologic analysis of the local aquifer materials.

This report presents a brief description of the geotechnical, sampling, and laboratory analysis programs with reference to the Task 25 Technical Plan (ESE, 1988a, RIC#88293R10). Documentation is provided for all new borings and wells installed in the Task 25 study area under the Composite Well Program (ESE, 1988a, RIC#88104R04).

To facilitate the hydrogeologic and water quality interpretations in the vicinity of the NBCS and NWBCS, a detailed characterization of the geologic units of concern was carried out. This analysis included the quaternary unconsolidated sediments and the Denver Fm. The geologic interpretation of quaternary unconsolidated sediments presented in this report is that of Morrison-Knudsen Engineers, Inc. (MKE, 1988). A

detailed study of Denver Fm geology, including cross-sections, structure, and isopach maps, is also presented in this report.

Unconsolidated sediments of 100-ft thick or less overlie the bedrock at RMA. These sediments are primarily alluvial in nature and include from oldest to youngest, the Verdos, Slocum, Louviers, Broadway, Piney Creek, and Post-Piney Creek. Overlying these alluvial sediments over most of the Task 25 study area is a blanket of eolian material.

The Denver Fm is the other geologic unit of primary concern in the Task 25 study area. The Denver Fm has been described in terms of its depositional environment, sandstone morphologies, and correlations of sandstone units within the formation. The depositional environment of the Denver Fm has been interpreted previously as a low-energy, non-marine fluvial environment. The interpretation presented in this report confirms that interpretation. A correlation of sandstone units within the Denver Fm is accomplished using a laterally continuous lignitic interval as a stratigraphic marker. These sandstone units are defined as hydrostratigraphic zones using geologic, water level and water quality data. Within the Task 25 study area, the Denver Fm has been subdivided into five hydrostratigraphic zones of interest.

The alluvial aquifer is discussed in terms of recharge, ground-water movement, and discharge. In some localized areas, where the bedrock surface contains sandstone and siltstone lenses, the alluvium and Denver Fm can be difficult to distinguish. Very little variation in water levels is noted between the wettest and driest quarters. The saturated thickness map indicates areas of thin or absent saturated alluvium, as well as the extent of paleochannels which may be up to 30 ft thick in the Task 25 study area. Reanalysis and evaluation of aquifer test data was accomplished under Task 36 and the pertinent data from that analysis are included in this report. It appears from the data that the alluvial aquifer responds as an unconfined aquifer in most cases, but

in some areas acts as an unconfined aquifer with a delayed yield. Transmissivity values in the alluvial aquifer ranged from approximately 6,000 gpd/ft to 79,000 gpd/ft.

The Denver Fm consists of a system of interbedded sandstones, siltstones, and clayshales. These sediments cause a high degree of variability in observed aquifer parameters. Flow within sandstone units is predominantly updip although potentiometric differences between sandstone units in the study area generally indicate the potential for some downward ground-water movement.

The nature and extent of ground-water contamination in both the alluvium and Denver Fm is presented in this report. Wherever possible, comparisons are made to data presented in previous reports. The Task 25 program included more wells and a more extensive list of analytes than any previous study in this area. Isoconcentration maps are provided for a large number of compounds including DIMP, DBCP, DCPD, the combined organosulfur compounds, 1,4-oxathiane, 1,4-dithiane, dieldrin, endrin, chloroform, trichloroethene, tetrachloroethene, 1,2-dichloroethane, arsenic, chloride, and fluoride. Numerous point plots are also included for compounds with less frequent detections. The isoconcentration water quality maps define migration pathways in the Task 25 study area within the alluvial aquifer. Trend analysis in a number of wells with a relatively long sampling history indicate that concentrations upgradient of the boundary systems have been fairly constant. Downgradient of the NBCS, however, there has been a general decrease in contaminant concentrations over the last 10 years. The variations do vary with the contaminant and the values for some contaminants do appear to be increasing in some wells.

Denver Fm assessment indicates that the contaminants with the widest distribution are benzene, chlorobenzene, chloroform, DIMP, dieldrin, and the combined organosulfur compounds, although detections are generally sporadic. Downward vertical gradients, between hydrostratigraphic zones, appears to have resulted in relatively low levels of contamination migrating downward within the Denver Fm. The hydrostratigraphic zones exhibiting the highest concentrations are zones 1 and 2.

These hydrostratigraphic zones subcrop at the NBCS or immediately upgradient of the system.

1.0 INTRODUCTION

The Rocky Mountain Arsenal (RMA) occupies 27 square miles in southern Adams County, Colorado, and lies within the Denver Metropolitan area north of the City of Denver and east of Commerce City, Colorado (Figure 1.0-1). Since RMA began operation in 1942, it has been a site for the manufacture and demilitarization of chemical incendiary munitions and the manufacture of industrial chemicals, primarily pesticides and herbicides. A detailed account of disposal practices associated with these operations and an overview of resulting soil and water contamination are presented in the Task 1 Technical Plan [Environmental Science and Engineering (ESE), 1985, RIC#85127R07)].

The disposal practices of the Army and leaseholders occurred over approximately a 40-year period and led to the widespread introductions into the ground water of a host of organic and inorganic contaminants, most notably, chloride, fluoride, diisopropylmethylphosphonate (DIMP), dicyclopentadiene (DCPD), dibromochloropropane (DBCP), organosulfur compounds, organochlorine pesticides, volatile aromatic compounds, and volatile organohalogen compounds. Ground-water monitoring programs conducted since the mid-1970's have detected some or all of these compounds in the vicinity of the north and northwest boundaries.

This report presents ground-water quality and water level data collected during fiscal year 1987 (FY87), which is October 1986 through September 1987, for the north and northwest portions of RMA. The Task 25 study area includes all or parts of Sections 19, 22, 23, 24, 27, and 28 onpost at RMA and all or parts of Sections 13, 14, 15, 16, 18, 21, 22, and 28 offpost. The area of study is illustrated in Figure 1.0-2.

1.1 GROUND-WATER CONTAINMENT SYSTEMS

Based on data collected during the monitoring programs at RMA, a plan was developed over a number of years to ensure localized control of contaminant migration through the use of ground-water control systems located along RMA

boundaries. Three ground-water containment systems (North, Northwest, and Irondale) began operation in 1982, 1984, and 1981, respectively (Figure 1.0-2). The North Boundary Containment System (NBCS) and Northwest Boundary Containment Systems (NWBCS) are located within the Task 25 Study Area and a summary of the configuration of these systems is presented below.

1.1.1 NORTH BOUNDARY CONTAINMENT SYSTEM

The NBCS is located just south of the north boundary of RMA in Section 23 and 24 as shown in Figure 1.0-2. NBCS consists of a dewatering system to withdraw contaminated ground water; a soil-bentonite barrier to separate contaminated and treated ground water and impede offpost migration; a carbon-adsorption treatment system to remove organic contaminants; and a recharge system to return treated ground water to the alluvial aquifer.

The NBCS was constructed in two phases during 1978 and 1981. The existing soil-bentonite barrier is 6,740-feet (ft) long and approximately 3-ft wide, with a design hydraulic conductivity of 1×10^{-7} centimeters per second (cm/sec) or less. Originally, the NBCS incorporated 54 dewatering wells upgradient from the soil-bentonite barrier to intercept ground water approaching the RMA north boundary. Thirty-five of the dewatering wells are screened in the alluvial aquifer and 19 dewatering wells were screened in Denver Formation (Fm) sandstone units beneath the system. The Denver Fm dewatering wells had not been used since the fall of 1984 and were recently closed. Thirty-eight recharge wells originally returned treated water to the alluvial aquifer (Figure 1.1-1) and were recently augmented by 10 recharge trenches along the western portion of the system.

The dewatering wells are divided into three collection manifolds, designated A, B, and C, that intercept and dewater separate segments of the aquifer. Figure 1.1-1 illustrates the manifold alignment. Ground water from each manifold flows to a separate sump prior to entering the carbon-adsorption treatment system (Figure

1.1-2). Treated ground water is discharged to a common sump prior to recharge. The average flow through the system is about 200 to 300 gallons per minute (gpm).

1.1.2 NORTHWEST BOUNDARY CONTAINMENT SYSTEM

The NWBCS is located along the northwest boundary of RMA in the southeast quarter of Section 22 (Figure 1.0-2). Construction of the NWBCS began in March 1983, and the system became operational in 1984. The purpose of this system was to intercept and remove DBCP and other organic compounds from a plume of contaminated ground water originating within or to the southeast of Section 26. The system consists of a line of 15 upgradient dewatering wells and 21 downgradient recharge wells (Figure 1.1-3), and a carbon-adsorption type treatment facility (Figure 1.1-4).

Along the northeast part of the system, between the line of dewatering and recharge wells, is a soil-bentonite barrier approximately 900-ft long, 3-ft wide, and up to 30-ft deep. The soil-bentonite barrier was constructed of a bentonite and native soil mix to provide a hydraulic conductivity of 1×10^{-7} cm/sec. The barrier is anchored 2 ft into the Denver Fm and intercepts a saturated alluvial thickness of approximately 10 ft. Southwest of the soil-bentonite barrier, the bedrock surface decreases in elevation, causing the thickness of saturated alluvium to increase to approximately 30 ft. The system was designed to withdraw, treat, and inject about 1,500 gpm. Currently, the system flow is 500 to 700 gpm, and a predominant amount of the recharge is in the southwest part of the system.

1.2 SAMPLING HISTORY

Ground-water levels have been monitored and water quality has been tested in the boundary containment system areas since the late 1970's. Much of the early monitoring was conducted to investigate contaminant migration and obtain design criteria for the boundary containment systems. Following construction and operation of the NBCS in 1982 and the NWBCS in 1984, formal ground-water monitoring

programs were established using monitoring wells which had been installed during the investigative projects.

The monitoring programs for both systems required water quality and water level data acquisition and evaluation on a routine basis. The historical NBCS monitoring program consisted of 190 well sites for water levels and 60 to 80 well sites for water quality. These ground-water samples were routinely analyzed for DIMP, DCPD, DBCP, chlorinated pesticides, organosulfur compounds, chloride, and fluoride. The NWBCS program consisted of monitoring 117 well sites for water levels and 45 well sites for water quality. Water samples for this program were analyzed for DIMP, DBCP, chlorinated pesticides, chloride, and fluoride. Contaminant isoconcentration and water level elevation contour maps for both the NBCS and NWBCS were prepared by the Program Manager Staff Office (PMSO) at RMA and the U. S. Army Corps of Engineers Waterways Experiment Station (WES) for FY85 and FY86 (PMSO, 1987a, RIC#87320R01; PMSO, 1987b, RIC#88054R01). In FY86 the list of analytes was expanded to include many of the volatile organohalogens, volatile aromatics, and chlorinated pesticides that are included in the present analytical schedule. This analytical schedule represents a suite of the priority contaminants that are potentially of interest as a result of past manufacturing and disposal activities at RMA. The monitoring of these key contaminants in ground water allows an evaluation of the rate of movement and extent of contamination approaching the containment systems.

1.3 PROJECT OBJECTIVES AND APPROACH

The objectives of Task 25 include monitoring ground-water levels and contaminant concentrations in the alluvium and Denver Fm in the vicinity of the NBCS and NWBCS, defining contaminant transport pathways in these areas, and providing water quality and hydrologic data for the operation of the NBCS and NWBCS. In addition to tracking contaminant distributions defined by previous programs, Task 25 evaluates the distribution of certain organic analytes such as volatile organohalogens, volatile aromatics, additional chlorinated pesticides, and organosulfur compounds along with

others which were not routinely analyzed for prior to 1986. The data used to achieve these objectives were obtained in the following way:

- Development of a detailed three-dimensional understanding of alluvial and Denver Fm geology in the Task 25 study area;
- Monitoring of the potentiometric surface upgradient and downgradient of NBCS and NWBCS in both the alluvium and Denver Fm on a quarterly basis;
- Use of new and historical aquifer test data to assess the hydrologic characteristics of the alluvium and Denver Fm in the Task 25 study area; and
- Analysis of ground-water quality samples collected from monitoring wells upgradient and downgradient of NBCS and NWBCS on a quarterly basis.

Data used to prepare the assessments presented in this report include lithologic logs, geophysical logs, and well construction information for all Denver Fm wells and many alluvial wells located in the study area; quarterly water level and water quality data collected during FY87; and available new and historical aquifer test data for the alluvium and Denver Fm.

The evaluation of this data represents a detailed assessment of the extent of contamination and an evaluation of the rate of contaminant movement in this area of RMA.

1.4 REPORT ORGANIZATION

This report includes three major divisions contained within three separate volumes. The main text, contained in Volume I, is separated into six major sections. These include Section 1.0, an introduction; Section 2.0, a presentation of data collection methodology, well installation, and monitoring networks; Section 3.0, a description of alluvial and Denver Fm geology; Section 4.0, an assessment of alluvial and Denver Fm hydrogeology; Section 5.0, an evaluation of local organic and inorganic

contaminant distribution; and Section 6.0, the conclusions. Figures of a general descriptive nature referred to in the text are presented with the text.

Volumes II and III contain Appendices A and B, respectively. The data bases that support the interpretations and figures presented in the text are contained in Appendix A. Appendix B contains all geologic cross sections and maps, quarterly water table maps, and contaminant distribution maps, as well as any additional figures referred to in the text.

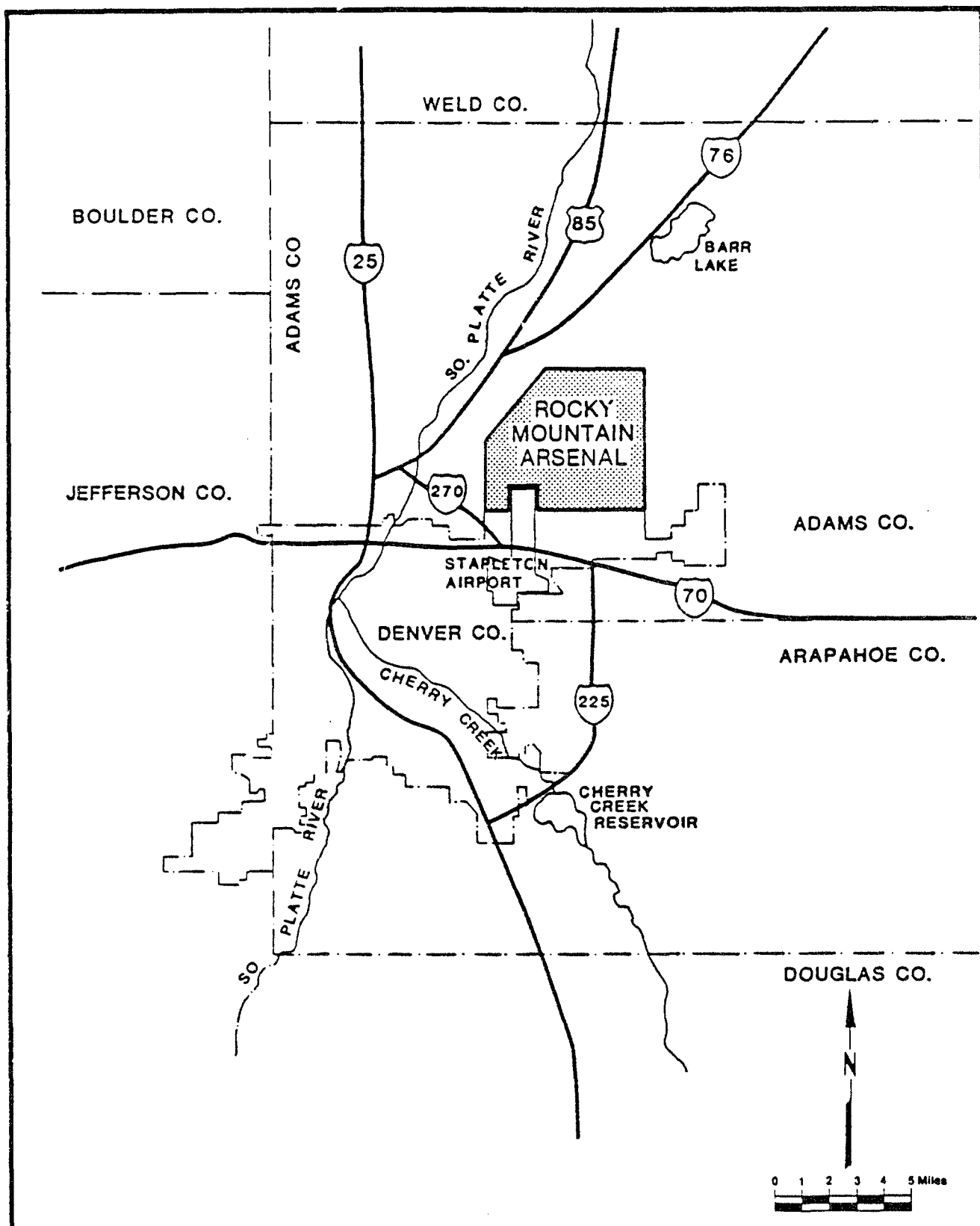
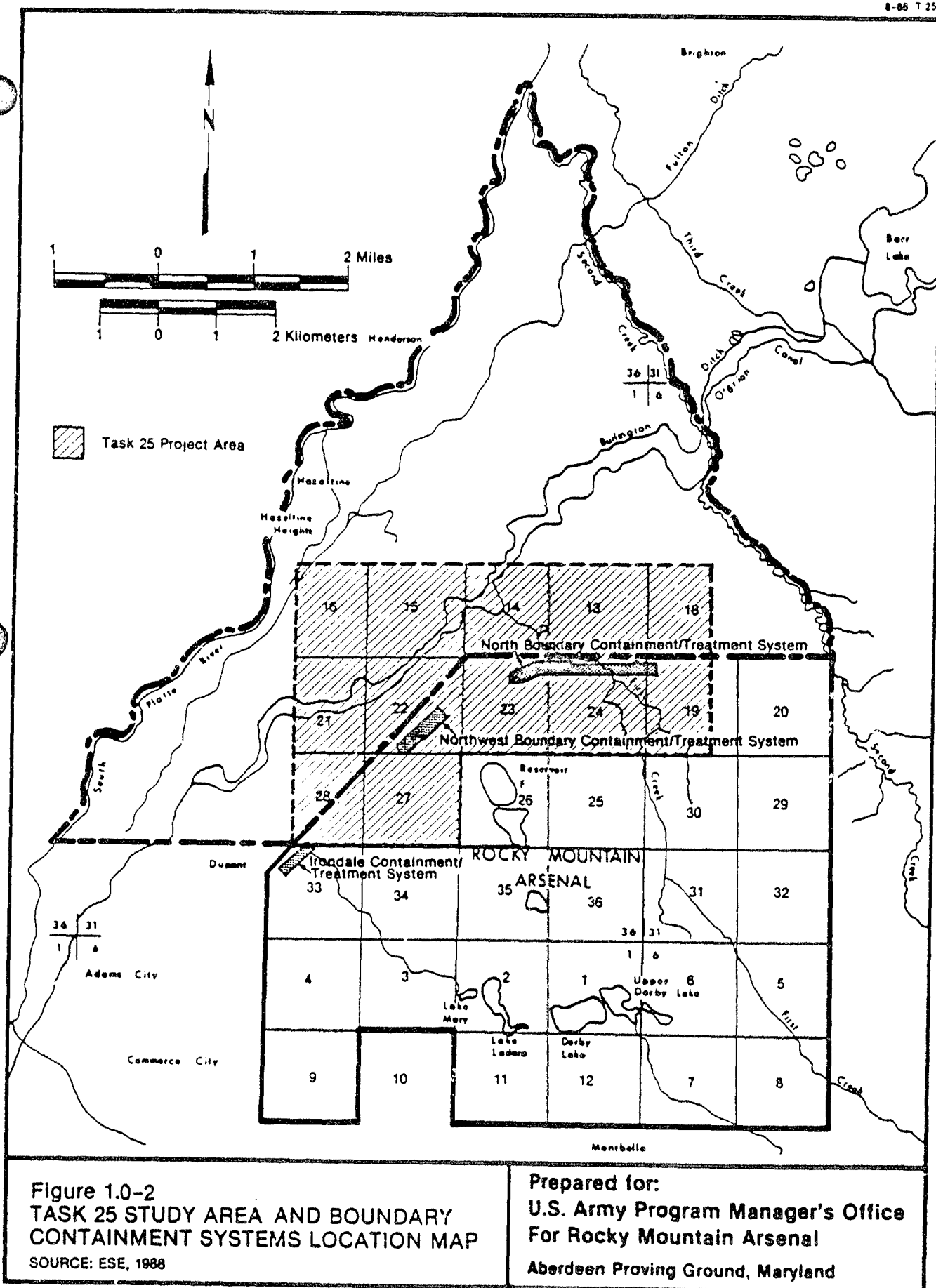


Figure 1.0-1
 LOCATION MAP OF
 ROCKY MOUNTAIN ARSENAL
 SOURCE: ESE, 1988

Prepared for:
 U.S. Army Program Manager's Office
 For Rocky Mountain Arsenal
 Aberdeen Proving Ground, Maryland



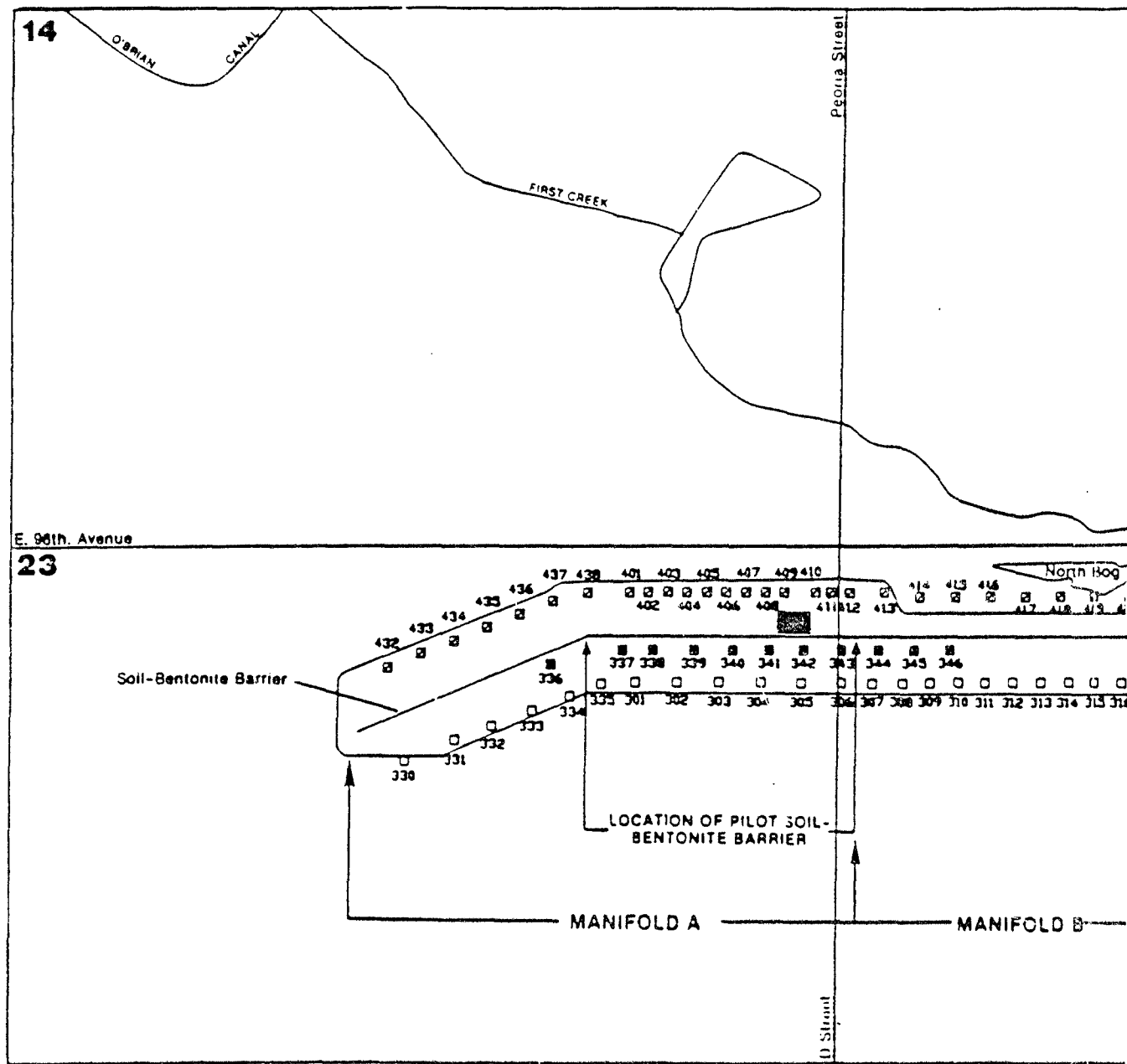
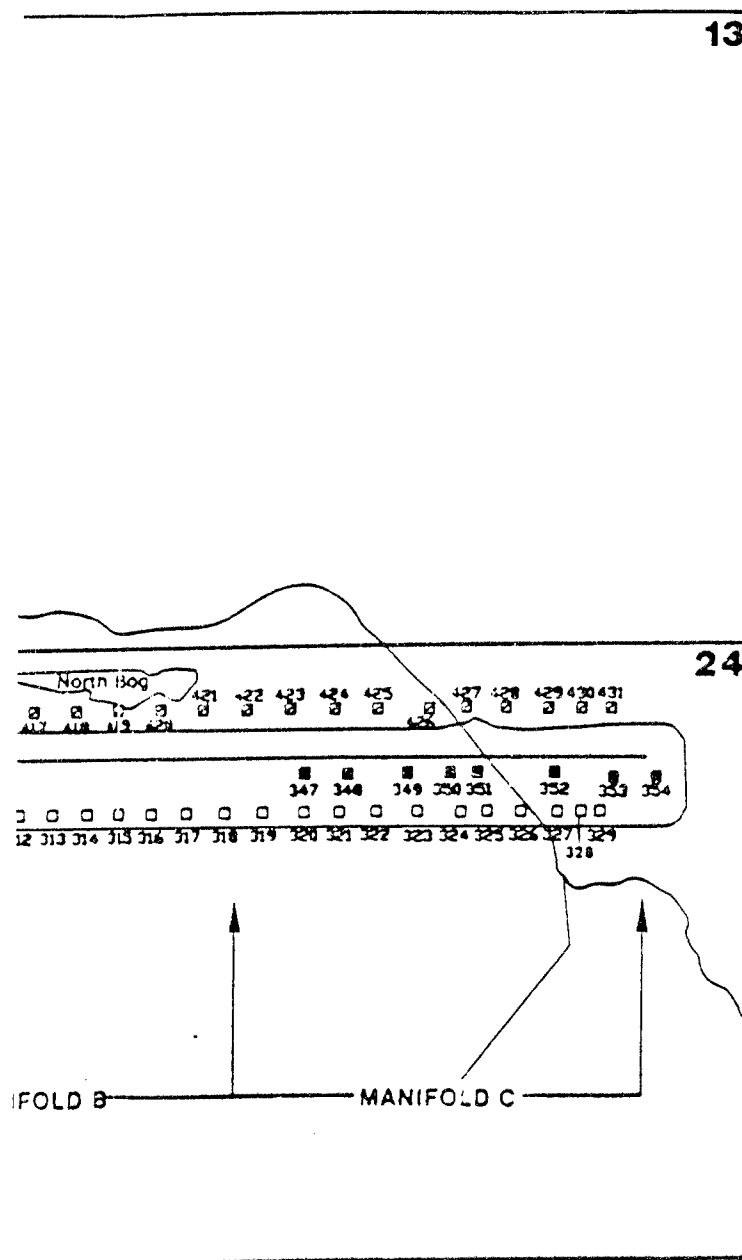
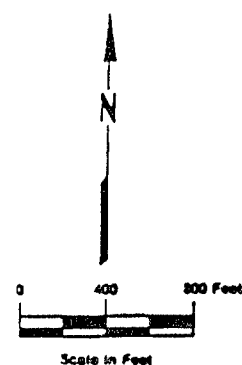


Figure 1.1-1
 NORTH BOUNDARY CONTAINMENT SYSTEM
 SOURCE: ESE, 1988

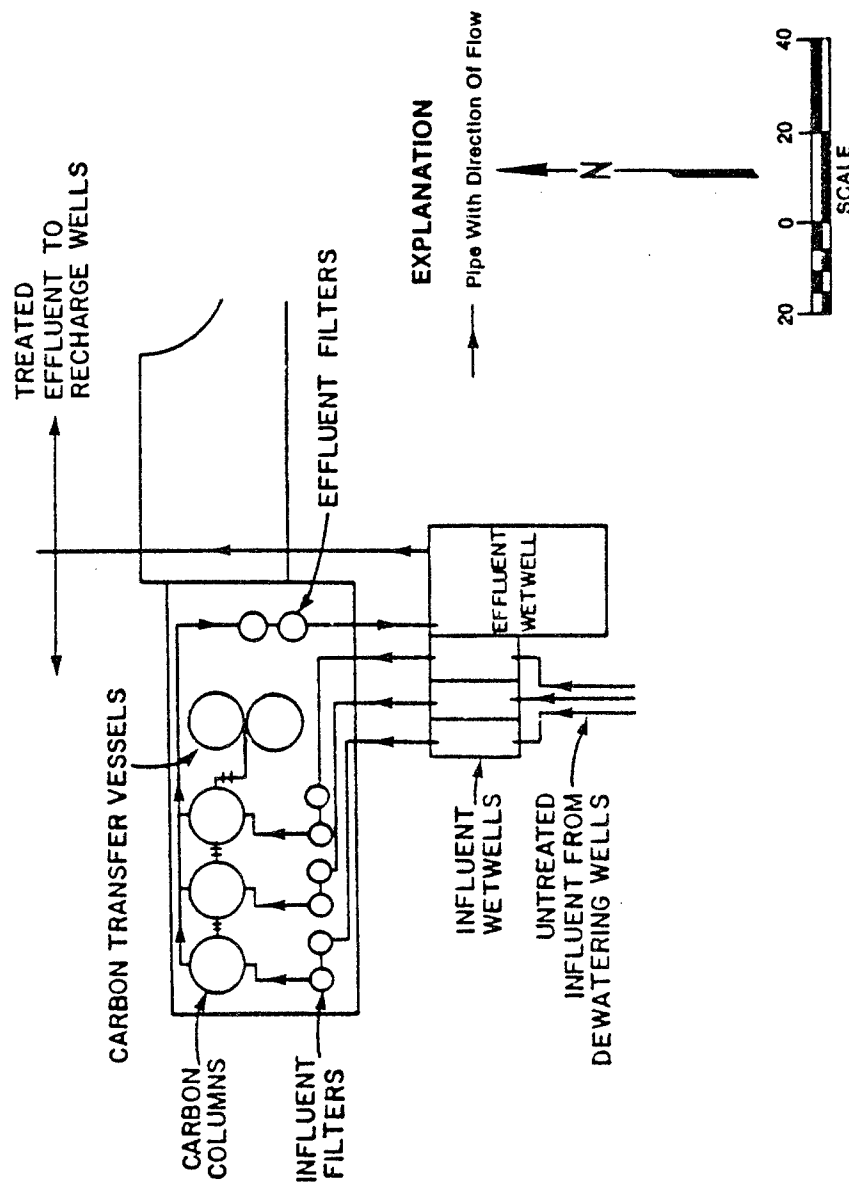


EXPLANATION

- ☒ Recharge Wells
- ☐ Alluvial Dewatering Wells
- ☒ Denver Dewatering Wells
- ☒ Location Of Carbon-Adsorption Treatment System



Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland



Prepared for:
 U.S. Army Program Manager's Office
 For Rocky Mountain Arsenal
 Aberdeen Proving Ground, Maryland

Figure 1.1-2
 NORTH BOUNDARY GROUND-WATER TREATMENT FACILITY

SOURCE: ESE, 1988

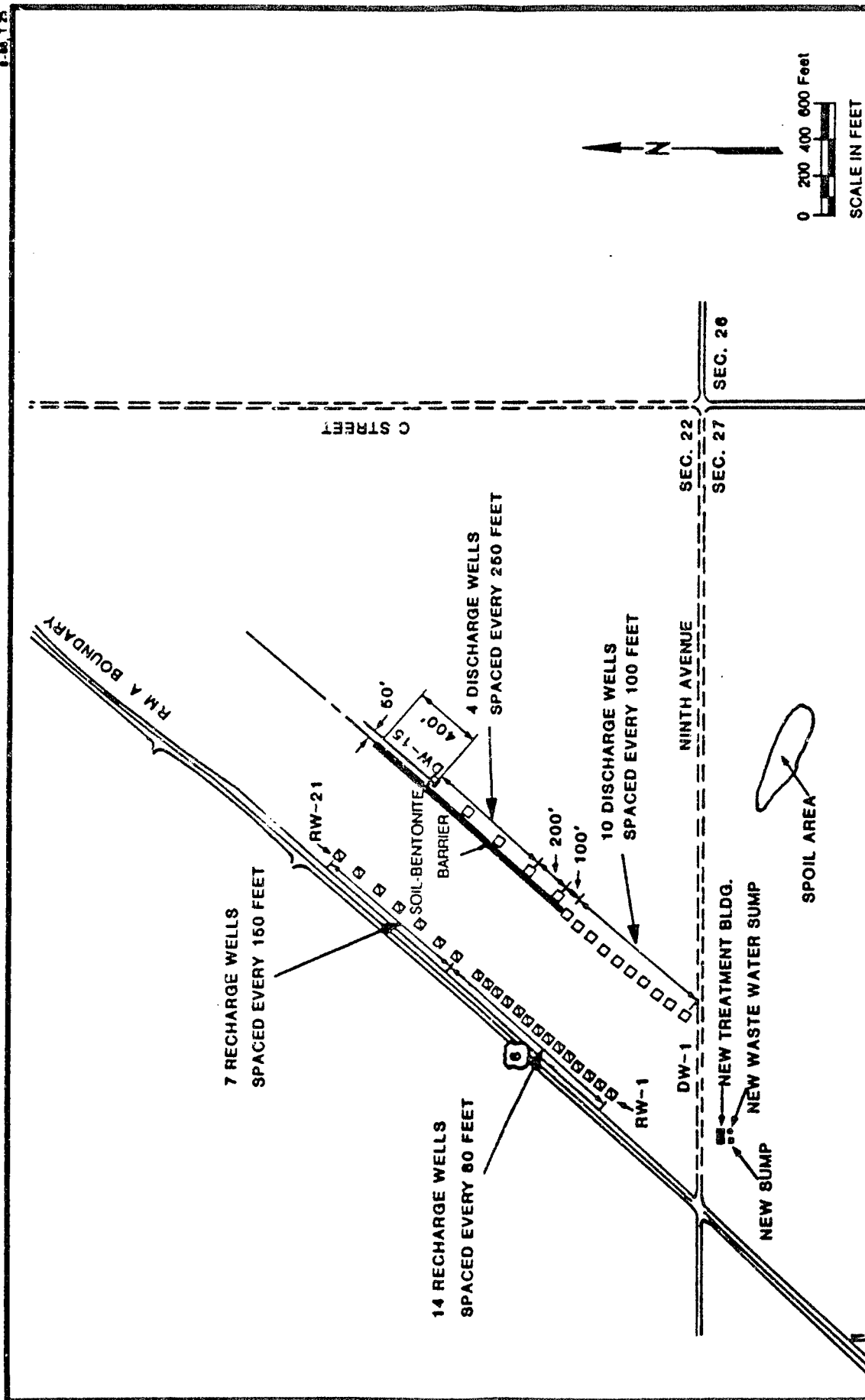


Figure 1.1-3
NORTHWEST BOUNDARY CONTAINMENT SYSTEM

SOURCE: ESE, 1988

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For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

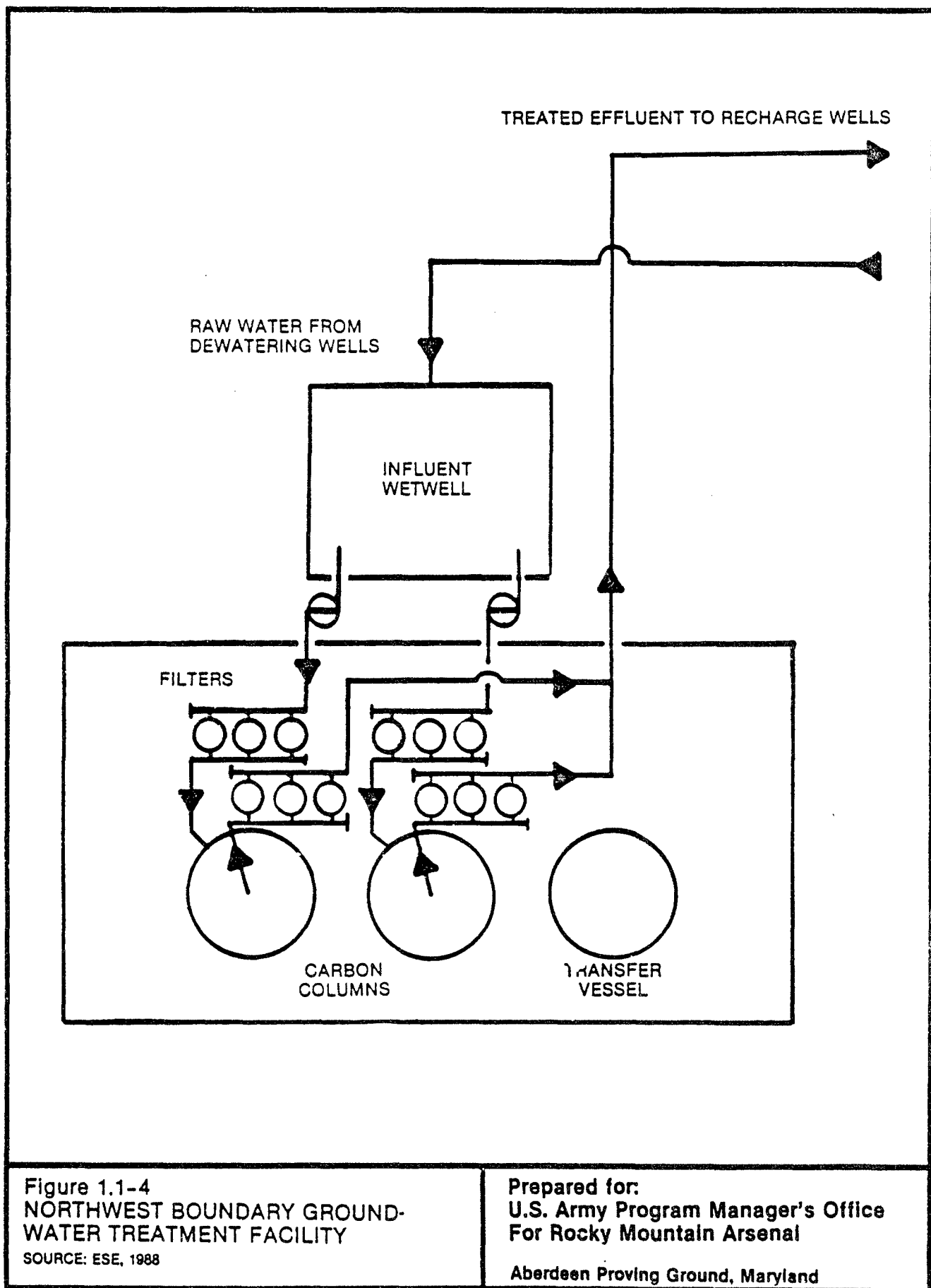


Figure 1.1-4
NORTHWEST BOUNDARY GROUND-
WATER TREATMENT FACILITY
SOURCE: ESE, 1988

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Aberdeen Proving Ground, Maryland

2.0 DATA COLLECTION

Task 25 data collection efforts are an extension of the geotechnical work performed at RMA over the last several years. The first phase of Task 25 consisted of an examination of the extensive data base available from previous and ongoing programs. A review was made of all pertinent information and reports on file at the RMA Information Center (RIC) and the U.S. Army Program Manager's Office-Rocky Mountain Arsenal Contamination Cleanup (PMO-RMA). Additional information was obtained from interviews of technical experts at PMO-RMA and WES. This research effort provided the information necessary to evaluate previously sampled wells, delineate contaminated areas, identify data gaps, and select water level and water quality monitoring sites. The evaluation of existing and newly generated data - including well logs, water quality, and aquifer test data - resulted in the development of a geological-hydrological framework for the alluvium and Denver Fm at RMA. This conceptual model has been used by Task 25 to assess the concentration and distribution of contaminants in the vicinity of NBCS and NWBCS.

The second phase of Task 25 consisted of collecting quarterly water level and water quality data and compiling that data into a comprehensive data base. Additional data have been obtained by drilling new wells and borings, obtaining rock and soil samples for analysis, and conducting aquifer tests. The Task 25 Technical Plan (ESE, 1988a, RIC#88293R10) provides an overview of the environmental setting and geotechnical program.

2.1 DESIGN OF THE GROUND-WATER MONITORING NETWORK

The monitoring well network was designed to satisfy the following objectives:

- Define the concentration and distribution of alluvial contaminants and any seasonal concentration fluctuations;
- Define alluvial water quality in the vicinity of the containment systems;
- Define Denver Fm water quality in the vicinity of the containment systems;

- Define contaminant flow paths in the Denver Fm, particularly in the vicinity of the containment systems;
- Define the rate of movement of contaminants in both the Denver Fm and alluvial sediments; and
- Assess the impact of the pumping and recharge operations in controlling local ground-water flow and contaminant transport in and around the containment systems.

The initial step in designing the monitoring network was to evaluate and incorporate a large number of existing wells in the Task 25 study area. These wells were evaluated for well construction under the Initial Screening Program Report, Task 4 (ESE, 1987b, RIC#87253R01). In addition, Task 44, the Rocky Mountain Arsenal Onpost/Offpost Ground/Surface Water Monitoring Program, designed a monitoring network that included wells within the study area. Because of this, the Task 44 information was included in the Task 25 evaluation.

Wells were installed within the Task 25 study area under the direction of several interrelated tasks, including Tasks 36, 39, and 44, as well as Task 25. All data collected in the Task 25 area, including data collected under Tasks 36, 39, and 44, are presented in this report. Sites for new wells were chosen to fill specific data gaps in the existing network. Upon review of these additional data requirements, several major objectives were formulated for the well installation program. These primary objectives were:

- To obtain additional water quality data in the alluvium and Denver Fm in the vicinity of the containment systems to help assess contamination patterns and the potential for contaminant bypass of the systems;
- To acquire additional water-level data in the alluvium and Denver Fm that would enable assessment of local flow patterns in the vicinity of the containment systems, including the interaction between aquifers;
- To obtain additional geologic data that would provide a more precise conceptual picture of the configuration of Denver Fm sandstone units and

primary alluvial channel features in the vicinity of the containment systems; and

- To collect additional hydrogeologic data to assist in estimating flow quantities and directions.

Completion records for each existing well included in the monitoring network were carefully examined to determine the relationship between screened intervals and hydrogeologic units. The primary objective of this review was to identify the specific hydrogeologic unit that each well monitors. An examination of wells within the alluvial network indicated that some of these wells extended into the Denver Fm beyond the 1 to 2 ft currently specified for construction of RMA alluvial monitoring wells. Although the overwhelming majority of these wells appeared to yield data representative of alluvial water quality and water levels, wells which might be partially representative of Denver Fm characteristics were identified. This effort was necessary to ensure the generation of accurate work products such as potentiometric surface and contaminant distribution maps.

A preliminary review of the available well completion and lithologic data was performed for each monitoring well. Each well was determined to be representative of either the alluvial aquifer, Denver Fm, or a composite of both. A number of wells are screened in both aquifer units and the ground water they monitor may be more representative of one or the other units or may be a nearly equal mixture of both. This situation was the result of two possible causes: the monitoring of thin alluvial saturated thicknesses or the monitoring of water table conditions in areas of unsaturated alluvium. A criterion was established to determine which aquifer these wells monitor. This criterion compared the percentage of screen length in each aquifer to the transmissivity of the lithologic units screened. From this information, the predominant aquifer monitored by each well was determined and five distinct well designation categories were generated. These designations, identified as Categories 1 through 5, are described in Appendix A. A general description of the numbered categories is provided below:

- Category 1 - These wells are considered strictly alluvial wells. Wells assigned to this category are screened across the alluvium and extend less than 3 ft into fine-grained bedrock. The majority of alluvial wells in the study area are designated as Category 1 wells.
- Category 2 - These wells are considered alluvial wells, but are either screened 3 to 6 ft into fine-grained bedrock, or have a minor percentage of the screened interval in direct contact with a subcropping bedrock sand unit.
- Category 3 - These wells have a major percentage of the screened interval within the Denver Fm, but because of the transmissivity differences between the alluvial and Denver Fm materials screened, water levels and water quality are more closely indicative of the alluvial aquifer.
- Category 4 - These wells also have a major percentage of their screened interval within the Denver Fm. Due to the similar transmissive characteristics of the alluvial and Denver Fm materials screened at these sites, these wells are thought to represent water level and water quality characteristics of both the Denver Fm and alluvial aquifer.
- Category 5 - These wells are screened entirely within the Denver Fm.

All data from wells within Categories 1 through 4 have been considered in the generation of alluvial water table and contaminant distribution maps. Similarly, data from wells within Categories 4 and 5 have been evaluated for inclusion into Denver Fm work products. There are a limited number of Category 4 wells within the Task 25 study area. The data from these wells were used for interpretative purposes. These data were included on both alluvial and Denver Fm maps where they appear to fit the local trends. Denver Fm wells are further delineated in Section 4.0 as to the specific hydrostratigraphic zone they screen.

2.1.1 ALLUVIAL AQUIFER MONITORING NETWORK

The alluvial aquifer monitoring networks used for this study are illustrated in Figures B-23A and B-24A. These maps show all existing and newly installed wells. Figure

B-23A presents the locations of water level monitoring wells. Figure B-24A presents the locations of water quality monitoring wells. The aquifer designation number assigned to each well is provided in Table A-1.

All alluvial wells installed in the study area, under the current Composite Well Program (ESE, 1987a, RIC#88104R04), are shown in Figure 2.1-1. All alluvial wells were installed in accordance with the Task 25 Technical Plan (ESE, 1988a, RIC#88293R10) and the Task 36 Technical Plan (ESE, 1988b, RIC#88063R08). Six upgradient and eleven downgradient alluvial aquifer wells were installed in the vicinity of the NBCS under the Composite Well Program. In the vicinity of the NWBCS, two upgradient and three downgradient alluvial aquifer wells were installed under Task 25.

Boreholes for well installation in the alluvial aquifer were drilled using hollow-stem augers. At new water quality well sites, continuous samples for logging were collected in polybutyrate tubes as the augers were advanced during drilling. Water quality wells were completed inside the hollow-stem augers across the entire saturated thickness of the aquifer. A typical alluvial well completion is shown schematically in Figure 2.1-2.

Each alluvial borehole was lithologically logged by a project geologist after drilling. The soil descriptions and depths contained on the logs conform to the requirements and procedures outlined in the Technical Plans for Tasks 25 and 36. All logs and well completion diagrams for the 11 Task 25 sites are presented in Appendix A.

In addition to the alluvial water quality wells installed under the various programs, Task 36 completed 10 alluvial piezometers directly adjacent to the soil-bentonite barrier of the NBCS. These wells were constructed of 2-inch 20 slot (0.02-inch) polyvinyl chloride (PVC) well screen and were installed specifically to monitor water levels on either side of the soil-bentonite barrier.

Downgradient wells and piezometers were screened sufficiently above the present water table to allow for accurate monitoring of any changes in the potentiometric levels in this area. Similarly, upgradient wells and piezometers were screened sufficiently below the water table to allow for future declines. Each well and piezometer was completed with a sand pack and bentonite seal and grouted to the surface in accordance with the specifications of Section 3.2 of the Task 36 Technical Plan. These wells and piezometers were used during the fourth quarter FY87 to obtain water quality samples.

The well locations, as defined by Universal Transverse Mercator (UTM) coordinates, and specific well completion data for each well site location are provided in Table 2.1-1. The general well locations, descriptions of the geologic conditions encountered, and siting rationale are discussed for each Task 25 well in Appendix A.

2.1.2 DENVER FM MONITORING NETWORK

The network of Denver Fm wells monitored for this study are presented in Figures B-23B and B-24B. These maps show the locations for all existing and newly installed wells. Figure B-23B presents the locations of water level monitoring wells. Figure B-24B presents the locations of water quality monitoring wells. Each Denver Fm well has been assigned to the zone in which the well is screened. The definition of these hydrostratigraphic zones within the Denver Fm are discussed in detail in Section 3.4 of this report.

Denver Fm wells were not installed under the Task 25 program, however, 6 upgradient and 18 downgradient Denver Fm wells at NBCS were installed as part of the Task 36, 39, and 44 programs. The well locations are shown in Figure 2.1-3. All Denver Fm wells were installed in accordance with the guidelines of the Task 36 Technical Plan.

Boreholes for bedrock wells were drilled using direct water rotary drilling, and mud was used when necessary. Before well installation, pilot boreholes were drilled and

Table 2.1-1. Well Completion Data for Newly Installed Alluvial Sites

Site Number	Well Number	UDN Location Coordinates		Ground Level Elevation (ft)	Elevation Top of PVC (ft)	Screen Interval* (ft BGL)	Top of Bentonite* (ft)	Top of Sand* (ft)	Depth to Bedrock* (ft BGL)
		North	East						
E-38	3/374	4413400.0	511822.4	5,117.97 5,136.62	5,120.63	9.0 - 25.0	5.0	8.0	26.0
E-39	Dry								
E-40	3/370	4413410.4	512795.7	5,117.30	5,119.89	4.5 - 26.0	2.0	3.0	26.0
E-42	3/369	4413408.2	513023.6	5,122.09	5,124.70	4.0 - 25.5	2.0	3.0	25.5
E-44	3/373	4413408.5	512613.1	5,112.28	5,116.57	4.5 - 25.5	2.0	3.5	25.0
E-46	3/377	4414016.7	513548.6	5,136.67	5,139.24	23.0 - 39.0	18.0	22.0	39.5
E-47	3/378	4414415.2	51396.5	5,137.73	5,140.07	24.0 - 33.0	19.0	23.0	35.0
E-53	3/387	4414428.8	513719.7	5,121.00	5,122.40	17.5 - 39.0	3.7	7.5	50.0
E-55	3/384	4412393.0	510613.2	5,121.80	5,123.40	33.5 - 50.0			64.0
E-63	3/389	4413396.0	512335.6	5,128.03	5,129.38	8.5 - 35.0	3.0	7.0	23.5
E-65	3/381	4413370.0	512355.8	5,110.73	5,112.04	7.5 - 28.5	3.0	4.0	28.0
E-66	3/386	4412278.8	510433.6	5,132.70	5,136.20	39.5 - 50.5			50.0
E-67	3/385	4412334.9	512233.9	5,115.10	5,116.70	29.9 - 51.5			51.0
E-73	3/391	4414015.6	513381.2	5,136.77	5,138.53	19.5 - 41.0	10.0	15.0	40.0
E-74	3/392	4414012.7	513737.9	5,135.81	5,137.00	13.0 - 29.5	3.5	8.5	28.0
E-76	3/383	4413428.1	513546.7	5,119.00	5,120.00	11.5 - 36.5	7.5	12.5	39.5
E-82	2/186	4411526.3	510785.2	5,127.30	5,127.80	35.1 - 56.0	20.0	24.5	56.0
E-83	2/185	4411365.4	510740.2	5,127.50	5,129.00	30.8 - 46.5	25.0	30.0	45.5
E-84	2/1231	4412702.8	513128.1	5,155.51	5,157.16	16.0 - 27.0	6.9	10.5	26.0
E-85	2/199	4412752.0	513710.3	5,152.83	5,156.09	8.5 - 29.0	2.5	5.0	28.0
E-86	2/200	4412598.5	513492.8	5,163.25	5,166.62	21.0 - 41.5	11.0	16.0	42.0
E-86	2/201	4412537.5	513264.0	5,160.51	5,162.06	20.5 - 46.5	10.0	15.0	45.0
E-23	2/232	4412665.3	512918.9	5,155.26	5,156.83	13.0 - 23.5	3.0	7.5	23.0
E-53	2/220	4411717.3	512838.2	5,176.26	5,178.00	28.2 - 39.0			38.8
E-71	2/209	4412818.2	512963.7	5,133.40	5,136.90	75.2 - 81.0	18.0	22.5	12.0
E-72	Dry			5,152.72					
E-74	2/196	4412035.3	513893.9	5,153.80	5,155.90	16.5 - 27.5	6.0	11.0	25.5
E-75	2/223	4412417.7	513033.6	5,163.11	5,164.67	15.5 - 31.5	6.0	11.0	30.0
E-3	2/112	4413052.9	513002.7	5,149.07	5,150.33	8.0 - 18.0	3.0	6.5	
E-5	2/213	4413052.0	512883.7	5,165.62	5,167.10	10.0 - 20.0	3.0	4.0	
E-7	2/214	4413024.8	512622.4	5,147.46	5,149.00	10.0 - 20.0	3.0	8.0	
E-8	2/215	4413038.2	512672.2	5,146.68	5,148.12	8.5 - 18.5	3.0	7.0	
E-10	2/216	4413044.1	512803.7	5,144.86	5,146.50	8.1 - 18.5	3.0	7.0	
E-12	2/217	4413065.3	513043.7	5,149.10	5,150.76	10.5 - 20.5	4.5	8.5	
E-14	2/192	4412110.4	513441.5	5,151.63	5,153.25	13.0 - 23.0	6.5	11.0	
E-16	2/193	4413066.4	513390.0	5,165.49	5,167.27	7.5 - 18.0	3.0	6.5	
E-17	2/194	4413066.4	513563.1	5,163.32	5,165.08	6.0 - 16.0	3.0	4.0	
E-18	2/195	4413066.1	513741.0	5,140.53	5,142.05	4.0 - 14.0	2.0	3.0	

1 = Surveyed elevations.
2 = Screening intervals, depth to bedrock, and well completion data rounded to ± 0.5 ft. BGL = Below ground level.

Source: ESR, 1986.

lithologically and geophysically logged at all sites to determine stratigraphy and facilitate well construction. Downhole geophysical logging suites included spontaneous potential, natural gamma, and resistivity. Lithologic and geophysical logs for Task 25 wells are presented in Appendix A. Descriptive information for wells installed in the study area under other programs are provided in the Task 36 Report (ESE, 1989a, RIC#89103R01).

Precautions were taken during the installation of bedrock wells to prevent the possibility of cross-contamination between aquifers. The alluvial aquifer was sealed from lower aquifers by grouting conductor casing in place before drilling into bedrock. In the case of the Denver Fm wells, overlying units were sealed with casing prior to penetrating the target zone. During well completion, the lower units were isolated from upper units by placing a 5-ft bentonite plug above the well sand pack. These precautions assure that the water samples and water levels obtained from Denver Fm wells are indicative of the desired water bearing zone and that cross-contamination will not occur as a result of well installation.

Location coordinates and specific well completion data at each site are provided in Table 2.1-2. The general site locations, descriptions of the geologic conditions encountered, and siting rationale are presented for each drill site location in Appendix A.

2.2 SAMPLING AND ANALYSIS PROGRAM

Monitoring programs were designed to provide the water quality and hydrologic data required to support the comprehensive system assessment. Water levels were monitored and water quality samples were collected on a quarterly basis for FY87 and the resulting data are presented in this report. Table 2.2-1 presents the sampling chronology of the quarterly monitoring episodes. An overview of the water level and water quality monitoring program, along with the analytical program, is provided below.

Table 2.1-2. Well Completion Data for Denver Sites

Site Number	Well Number	UTM Location Coordinates		Gravel Level Elevation* (ft)	Elevation Top of PVC (ft)	Screen Interval* (ft BGL)	Top of Bentonite* (ft)	Top of Sand* (ft)	Depth to Bedrock* (ft BGL)
		North	East						
B-32	23218	4413163.2	513139.1	5,169.43	5,151.79	47.6 - 58.0	47.0	45.5	22.0
B-33	23219	4413179.1	513140.6	5,168.10	5,169.62	63.5 - 76.0	56.5	60.0	22.0
B-34	26191	4413170.6	513108.1	5,179.91	5,161.95	33.0 - 44.0	26.5	31.5	17.0
B-36	37376	4413227.2	51393.9	5,176.65	5,178.07	40.5 - 51.0	36.5	39.0	31.0
B-38	37379	4413670.3	511831.2	5,118.70	5,120.21	79.5 - 55.5	33.5	38.0	27.0
B-39	37380	4413680.9	511841.2	5,119.00	5,120.22	66.5 - 75.0	56.0	59.0	27.0
B-39	37387	4413677.8	512358.2	5,135.76	5,137.07	77.0 - 43.0	28.0	32.5	17.0
B-39	37388	4413690.3	512358.6	5,135.60	5,137.03	70.0 - 86.0	60.0	64.0	17.0
B-40	37371	4413607.5	512586.5	5,117.76	5,119.93	28.5 - 39.0	23.0	27.5	26.0
B-46	37372	4413610.1	512577.4	5,117.67	5,119.61	61.5 - 88.5	56.0	60.5	26.0
B-63	37390	4414016.7	513568.6	5,316.67	5,128.96	40.0 - 46.0	36.0	39.0	23.5
B-69	4413264.8	512760.9	5,160.07						
B-73	4414015.6	513383.2	5,135.69						
B-76	4414012.7	513377.0	5,136.93						
B-19	4413167.9	512613.1	5,164.83						26.0
B-20	4413165.9	512825.8	5,163.76		5,164.61	25.0 - 37.0	18.0	23.0	18.5
B-21	4413165.9	512825.8	5,162.90		5,164.15	52.5 - 58.0	4.0	49.0	18.5
B-26	4413167.5	512943.6	5,150.50		5,152.01	37.0 - 36.0	25.5	31.0	27.0
B-27	4412976.3	513093.9	5,153.80		5,155.90	52.0 - 62.9	42.0	47.0	
B-27	4412878.2	512963.7	5,167.80		5,169.67	33.5 - 39.0	26.5	30.5	18.0
B-28	4412876.9	512928.9	5,167.66		5,169.31	49.0 - 56.5	43.0	47.0	18.0
B-28	4413166.0	51299.2	5,139.27						15.0
B-33	4411722.9	512848.9	5,176.20		5,178.00	43.3 - 49.0	38.5	42.5	36.0
B-33	4411722.9	512848.9	5,176.20		5,177.20	59.6 - 70.3	52.5	51.5	36.0
B-71	4412878.2	512963.7	5,131.60		5,131.90	75.2 - 81.1	66.5	69.5	17.0
B-72	4412761.6	511276.4	5,133.20		5,135.00	96.5 - 102.0	85.5	97.0	12.0
B-72	4412819.4	512120.5	5,153.00		5,156.60	16.5 - 22.5	6.5	12.0	10.5
B-76	4412110.4	513683.5	5,152.90		5,156.66	112.5 - 123.5	101.0	107.5	10.5
B-76	4412115.4	513671.8	5,176.60		5,175.90	58.6 - 69.3	50.5	55.5	25.5
B-75	4412418.5	513070.2	5,176.60		5,175.90	79.1 - 116.3	67.5	73.5	25.5
B-75	4412418.9	513008.0	5,162.38		5,166.03	78.5 - 95.0	72.0	77.0	29.0
B-76	4413169.4	513006.1	5,162.17		5,164.27	106.5 - 115.5	95.5	101.0	30.0
B-76			5,151.20						21.5

† = Surveyed elevations.

* = Screening intervals, depth to bedrock, and well completion data rounded to ± 0.5 ft. BGL = Below gravel level.

Table 2.2-1. Quarterly Water Level and Water Quality Monitoring

Sampling Quarter	Data Collection	Dates Collected	Season
1st Quarter Fiscal Year 1987	Water Levels	November 1986	Fall 1986
	Water Quality	November 1986 - January 1987	
2nd Quarter Fiscal Year 1987	Water Levels	March 1987	Winter 1987
	Water Quality	March - April 1987	
3rd Quarter Fiscal Year 1987	Water Levels	June 1987	Spring 1987
	Water Quality	June - July 1987	
4th Quarter Fiscal Year 1987	Water Levels	September 1987	Summer 1987
	Water Quality	September - October 1987	

Source: ESE, 1988

2.2.1 WATER LEVEL MONITORING

Quarterly water levels were measured at each of the network wells within the study area. These are shown in Figures B-23A and B-23B for the alluvial and Denver Fm, respectively.

Water-level measurements were coordinated to collect data in the shortest possible time span; this was generally 10 days or less. This was done to obtain a set of measurements for each sampling period such that the resulting potentiometric maps are indicative of a distinct point in time. All water level measurements were obtained in accordance with the methodology and techniques described in the Technical Plan for Task 4 (ESE, 1986, RIC#87013R01).

A list of Task 25 wells monitored for water levels is presented in Table A-4 for alluvial wells and in Table A-5 for Denver Fm wells. In addition to these Task 25 wells, water level measurements obtained within the Task 25 study area under Tasks 4, 44, and 36 during FY87 have been integrated into the data base and are included on all maps.

2.2.2 WATER QUALITY SAMPLING

During the four quarters of FY87, water quality sampling was conducted on the water quality wells within the study area for the alluvium and Denver Fm (Figures B-24A and B-24B). Procedures for ground-water sampling, decontamination, and chain-of-custody were performed in accordance with the guidelines outlined in the Task 4 Technical Plan. A summary of these sampling procedures is presented in the Task 25 Technical Plan. Adherence to the guidelines provided uniform procedures for sampling. The guidelines permit the collection of samples that accurately reflect the water quality of the hydrostratigraphic zone of interest.

2.2.3 ANALYTICAL PROGRAM

Analyses of water quality samples were conducted jointly by ESE laboratories located in Gainesville, Florida and Englewood, Colorado. Both laboratories have undergone

a series of rigorous U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) certification procedures designed to ensure accurate and precise determination of the analytes considered to be the key contaminants associated with known source areas and the contaminants of interest. The laboratories have also implemented USATHAMA Quality Assurance procedures to continuously monitor the quality of the data. These steps assure that the Army is provided with reliable, statistically supportable, and defensible chemical data for ground water near the NWBCS and NBCS. A detailed discussion of analyst certification and quality assurance criteria is presented in the Task 4 Technical Plan.

The analyte schedule for Task 25 was determined in coordination with ongoing monitoring programs at RMA, which have identified the primary contaminants present in the ground water. These contaminants have been targeted for analysis by all Army monitoring programs. The target analyte list has been continually updated by evaluating gas chromatography-mass spectrometry (GC/MS) screening data obtained from regional monitoring programs and incorporating those contaminants which may require eventual remediation.

The analyte schedule for the Task 25 assessment was based upon evaluation of all applicable monitoring data, in particular, contaminant distribution data from the Task 4 Initial Screening Program. Based upon these evaluations, all RMA target organic analytes certified for water at that time were incorporated into the analytical schedule for the initial sampling quarter of Task 25. After the second sampling quarter, the compounds 1,4-oxathiane and 1,4-dithiane, as well as the organosulfur compounds chlorophenylmethyl sulfide (CPMS), chlorophenylmethyl sulfoxide (CPMSO), and chlorophenylmethyl sulfone (CPMSO₂), were dropped from the analyte list for wells in the vicinity of NWBCS. These compounds were not detected historically along NWBCS and were not detected in samples collected under Task 25 in significant or confirmable concentrations. These compounds continue to be monitored quarterly in the vicinity of NBCS and were also included in the regional monitoring program. The inorganic analytes - chloride, fluoride, sulfate, and arsenic - were incorporated into

the target analyte schedule to provide continuity with the historical data base initiated under the Operational Assessment Reports Program (Thompson *et al.*, 1985, RIC#86078R01 and PMSO, 1987a, RIC#87320R01). Some inorganic analytes, such as the inductively-coupled argon plasma (ICAP) metals, were not incorporated in the Task 25 analytical program. All target inorganic analytes continue to be determined in the regional and offpost monitoring programs. Field parameters, including pH, temperature, and specific conductance, were measured to ensure representative water samples and to assess the potential communication between aquifers.

Table 2.2-2 contains the final list of analytes, sample holding times, a reference to the specific methods for each parameter, and method certified reporting limits (CRL) for the ESE laboratories.

2.3 SLUG TESTS

Slug tests were performed on all newly installed Denver Fm wells within the study area as shown in Figure 2.1-3. These tests were conducted under Task 36 to obtain order of magnitude estimates for hydraulic conductivity for the Denver Fm sandstone units underlying NBCS. Slug in and slug out tests were conducted on all wells to provide two hydraulic conductivity values for comparison purposes.

The slug tests were performed by lowering or raising the water level in the well by rapidly removing or adding a fixed volume and measuring the resulting change in water levels with time. A nearly instantaneous rise (slug in) or decline (slug out) in water levels was simulated by displacing a known volume of water in a stainless steel cylinder. The cylinder was 10.2-ft long, had a 3-inch diameter, and displaced 0.5 cubic feet (ft³) of water. The water levels were measured with a 25 pounds per square inch (psi) pressure transducer, and the data were recorded on an Envirolab data logger directly as feet of water. The data logger allowed measurements to be taken at intervals as frequently as one second. Pertinent measurements included the initial water level in the aquifer prior to the test, the water level immediately after injection (or withdrawal), and the water level at a given time (t) after the injection (or

Table 2.2-2. Chemical Analysis - Task 25 Analytical Program (Page 1 of 2)

Analysis/Analytes	Hold Time	Level of Certification	Reference Methods	IOW Method CAN DEN	Analytical Method	Certified Reporting Limit (µg/l)	
						OW	DEN
<u>Organochlorine Pesticides</u>							
Aldrin	Extract as quickly as possible (no more than 7 days). Analyze within 30 days of extraction.	Quantitative	EPA 821	EPA	CAP GC/ECD	0.003	0.003
Endrin						0.052	0.060
Dieldrin						0.060	0.056
Isodrin						0.060	0.056
Hexachlorocyclopentadiene						0.070	0.083
p,p'-DDE						0.053	0.066
p,p'-DDT	1/4 days	Quantitative	EPA 821	TIB	PACK-GC/Hall	0.070	0.059
Chlordane						0.152	0.152
<u>Volatile Organohalogenes</u>							
Chlorobenzene	1/4 days	Quantitative	EPA 821	TIB	PACK-GC/Hall	0.58	1.36
Chloroform	1/4 days					1.40	1.88
Carbon Tetrachloride	1/4 days					2.40	1.69
trans-1,2-Dichloroethene	1/4 days					1.20	1.75
Trichloroethene (TRCLE)	1/4 days					1.10	1.31
Tetrachloroethene	1/4 days					1.30	2.76
1,1 Dichloroethene	1/4 days					1.10	1.85
1,1 Dichloroethane	1/4 days					1.20	1.93
1,1,1 Trichloroethane	1/4 days					0.61	2.07
1,1,2 Trichloroethane	1/4 days					1.70	1.09
1,1,2 Trichloroethane	1/4 days					1.00	1.63
Methylene Chloride	1/4 days					5.00	2.48
<u>Organosulfur Compounds</u>							
P-Chlorophenylmethylsulfone (CHMSO ₂)	Extract as quickly as possible (no more than 7 days). Analyze within 30 days of extraction.	Quantitative	EPA 821	EPA	PACK-GC/FID-S	4.70	2.26
P-Chlorophenylmethylsulfoxide (CHMSO)						4.20	1.98
P-Chlorophenylmethylsulfide (CHMS)						1.30	1.08
1,4-Dithiane						1.10	3.36
1,4-Oxathiane						2.00	1.35
Dimethyldithiide (HDS)						1.00	1.16
Benzothiazole						2.00	1.16

Table 2.2.2. Chemical Analysis - Task 25 Analytical Program (Page 2 of 2)

Analysis/Analytes	Hold Time	Level of Certification	Reference Methods	IMA Method	Analytical Method	Certified Reporting Limit (µg/l) GW DEN
<u>Volatile Aromatics</u>						
Toluene	14 days	Quantitative	EPA 602	W8 SS8	PACK-GC/PID	1.21 2.10
Benzene	14 days					1.34 1.92
Xylene (m)	14 days					1.35 1.04
Xylene (o,p)	14 days					2.47 1.34
Ethylbenzene	14 days					1.28 0.620
<u>DCPD/MIBK</u>						
Dicyclopentadiene	Extract as quickly as possible (no more than 7 days). Analyze extract within 30 days of extraction.	Quantitative	EPA 803	Z8 R8	CAP-GC/FTD	9.31 9.31 12.9 12.9
Methylisobutyl Ketone						
<u>DIMP/DMP</u>						
Diisopropylmethylphosphonate	Extract within 7 days of sampling.	Quantitative	EPA 622	T8 Q8	PACK-GC/FTD-P	10.5 15.20
Dimethylmethylphosphonate	Analyze within 30 days of extraction.					
<u>DBCP</u>						
Dibromochloropropane	14 days	Quantitative		V8 Q8	CAP-GC/ECD	0.130 0.130
<u>Metals</u>						
Arsenic	6 months	Quantitative	EPA 206	A8 W8	AA-Hydride Furnace-GW AA-Graphite Furnace-Den	2.50 2.50
<u>Inorganics</u>						
Chloride	28 days	Quantitative	EPA 300	X8 N8	Ion Chromatography	4,800 1,590
Fluoride	28 days				Ion Chromatography	1,200 1,000
Sulfate	28 days				Auto Analyzer-GW Ion Chromatography-DEN	10,000 5,000

Source: ESE, 1985.

withdrawal). Figure 2.3-1 is a schematic diagram illustrating the conditions in the well during a slug-in aquifer test. The relationship between field measurements and computational parameters H_o and $H_{(t)}$ are also indicated in this figure.

Data from the slug tests were evaluated using analytical procedures appropriate for the field boundary conditions encountered at individual Denver Fm well sites. The field conditions encountered during drilling and testing of Denver Fm wells were:

- Confined flow conditions;
- Water bearing sandstones of finite thickness and infinite extent, with respect to the radius of the wells;
- Fully penetrating well screens; and
- Transient or nonsteady state flow conditions during tests.

The Cooper et al. (1967) method of slug test analysis addresses all of the above boundary conditions and has been used for evaluation of test data in this study. This solution method is based upon the following assumptions:

- The aquifer is homogeneous, isotropic, of uniform thickness, and infinite areal extent;
- The aquifer is confined;
- The well is screened throughout the entire thickness of the aquifer; and
- Non-steady state flow conditions exist during the test.

For these assumptions, Cooper developed a solution of the basic equation for transient flow to a well, and prepared type curves to match with field data to determine transmissivity. The graphs, calculations, and Cooper type curves used for the slug test analyses are presented in the Task 36 Report (ESE, 1989a, RIC#89103R01).

To determine the aquifer transmissivity, the field data ($H_{(t)}/H_o$ versus time) were plotted on semilogarithmic paper at type curve scale and superimposed upon the type curves with the arithmetic axes parallel and coincident. That is, the value of

$H(t)/H_0 = 1$ for the field data lies on the horizontal axis of 1.0 for the type curve (Fetter, 1980). The field data plot was then translated horizontally to a position where the data best fit the type curves. In this position the vertical time value, t_1 , which overlays the vertical axis for $Tt/r_c^2 = 1.0$ was noted.

The transmissivity was found by substituting t_1 into the following equation:

$$T = \frac{1.0 r_c^2}{t_1} \quad (1)$$

where:

T = transmissivity
 r_c = the radius of the well casing
 t_1 = the time on the data coordinates at the value $\frac{Tt}{r_c^2} = 1.0$

and α is defined as:

$$\alpha = \frac{r_s^2}{r_c^2} \times S \quad (2)$$

where:

α = equation for the Cooper type curve
 S = storage coefficient
 r_s = radius of screen

The error in the determined value of T would be less than about 30 percent if the value of α for the chosen type curve is within two orders of magnitude of its actual value (Papadopoulos *et al.*, 1973).

The hydraulic conductivity was calculated from the slug test data by dividing the transmissivity by the aquifer thickness. The aquifer thickness was determined from the lithologic core logs and the electrical resistivity logs. The thickness was generally considered to include the entire interval of sandstone and/or siltstone regardless of the presence of minor clayshale interbeds.

2.4 TREATMENT PLANT MONITORING

Monitoring of the carbon-adsorption treatment system at NBCS and NWBCS was conducted during the study to evaluate the effectiveness of the system in removing organic contaminants from the influent ground water. The data were used primarily under Task 36 to evaluate the effectiveness of the NBCS and are available from the RIC. These data were included in interpretations of contaminant distribution near the containment systems and are, therefore, reflected on the isoconcentration maps presented in this report (Appendix B).

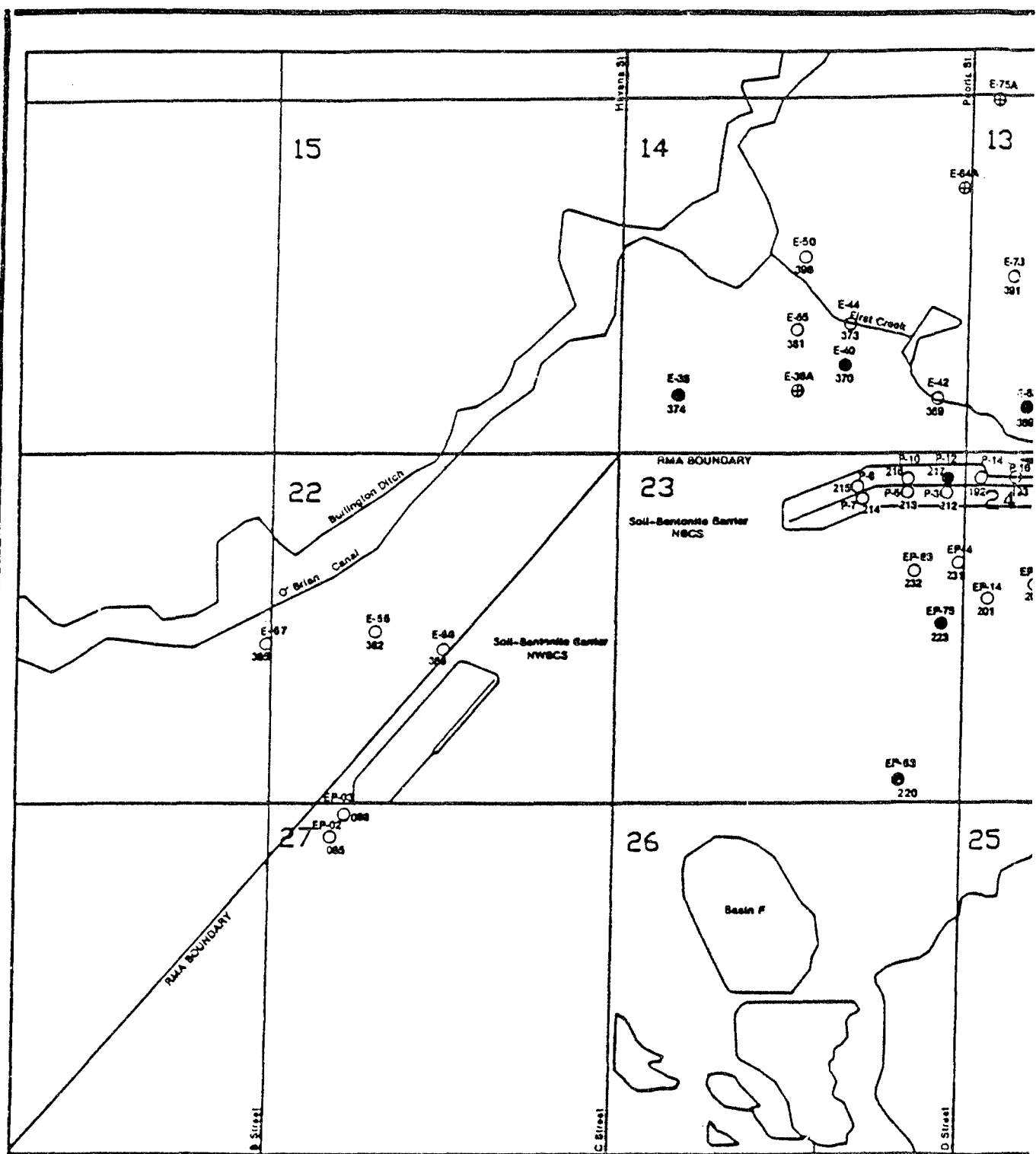
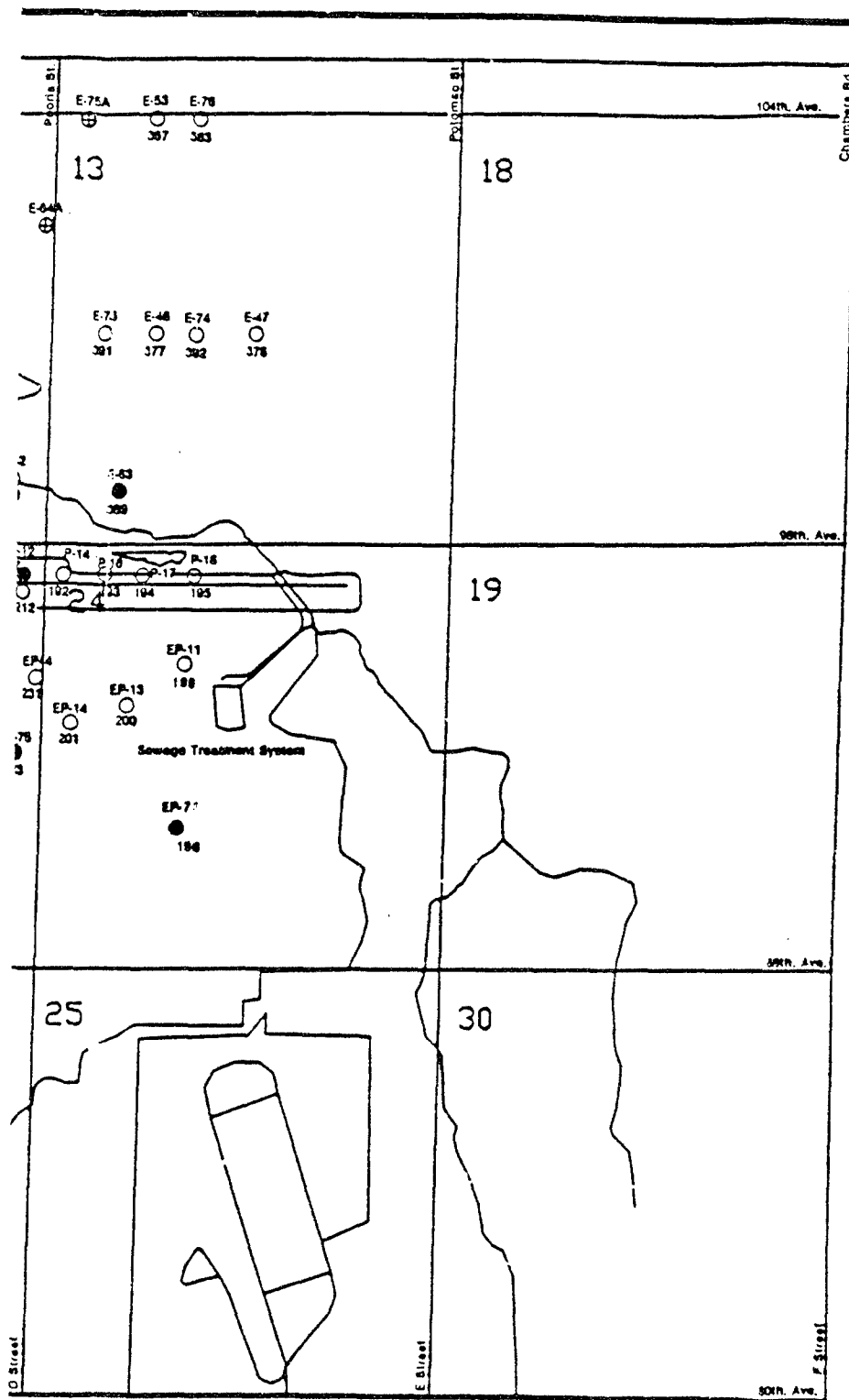


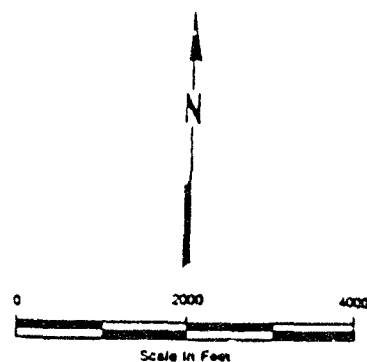
Figure 2.1-1
NEW ALLUVIAL SITES

SOURCE: ESE, 1988



EXPLANATION

- NWBCS NORTHWEST BOUNDARY CONTAINMENT SYSTEM
- NBCS NORTH BOUNDARY CONTAINMENT SYSTEM
- NEW ALLUVIAL WELL SITE
- NEW ALLUVIAL WELL(S) PAIRED WITH DENVER WELLS
- ⊕ ALLUVIAL BORING
- EP-# SITE NUMBER
- 37# WELL NUMBER



Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland

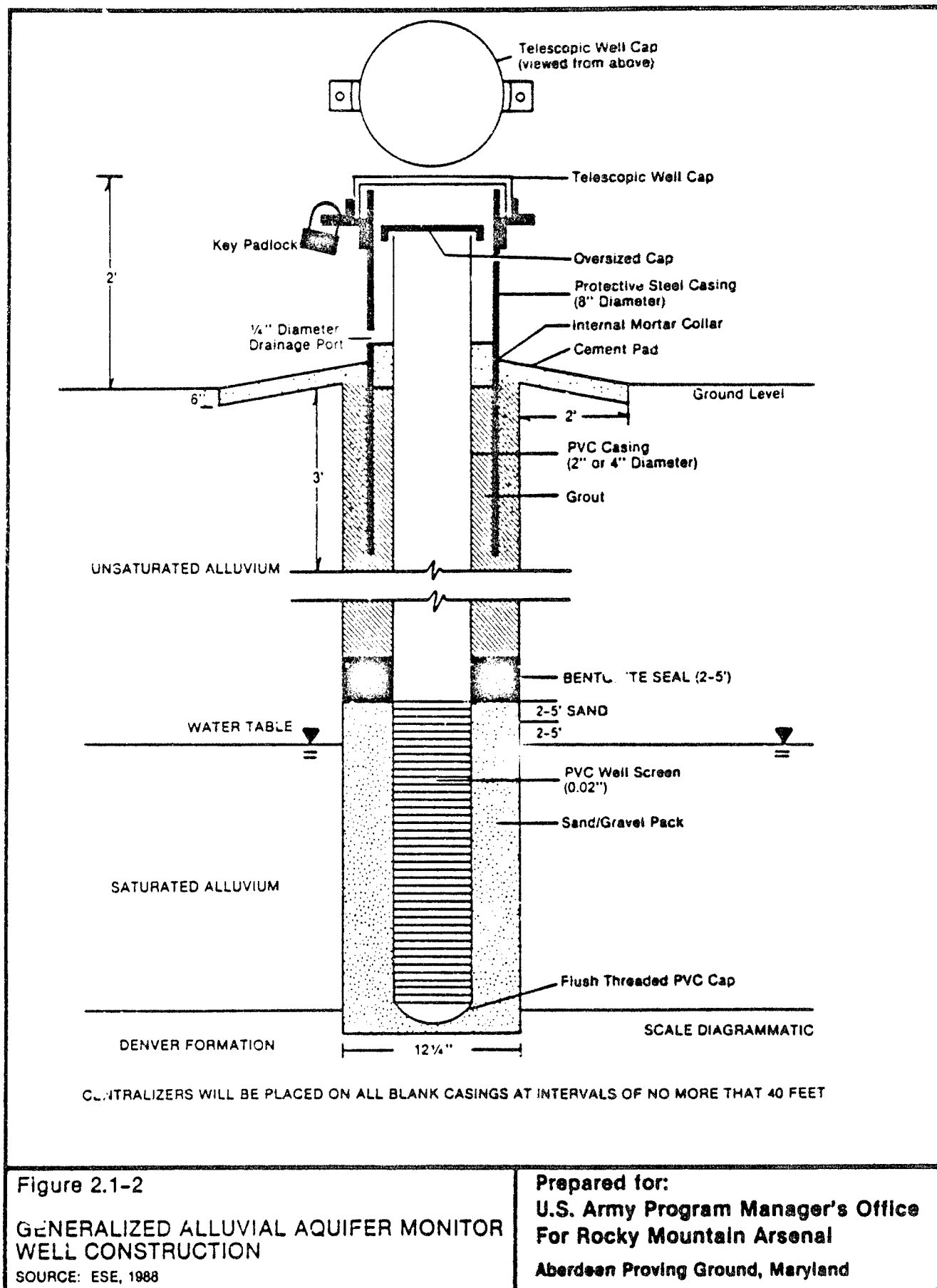


Figure 2.1-2

GENERALIZED ALLUVIAL AQUIFER MONITOR WELL CONSTRUCTION

SOURCE: ESE, 1988

Prepared for:

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For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland

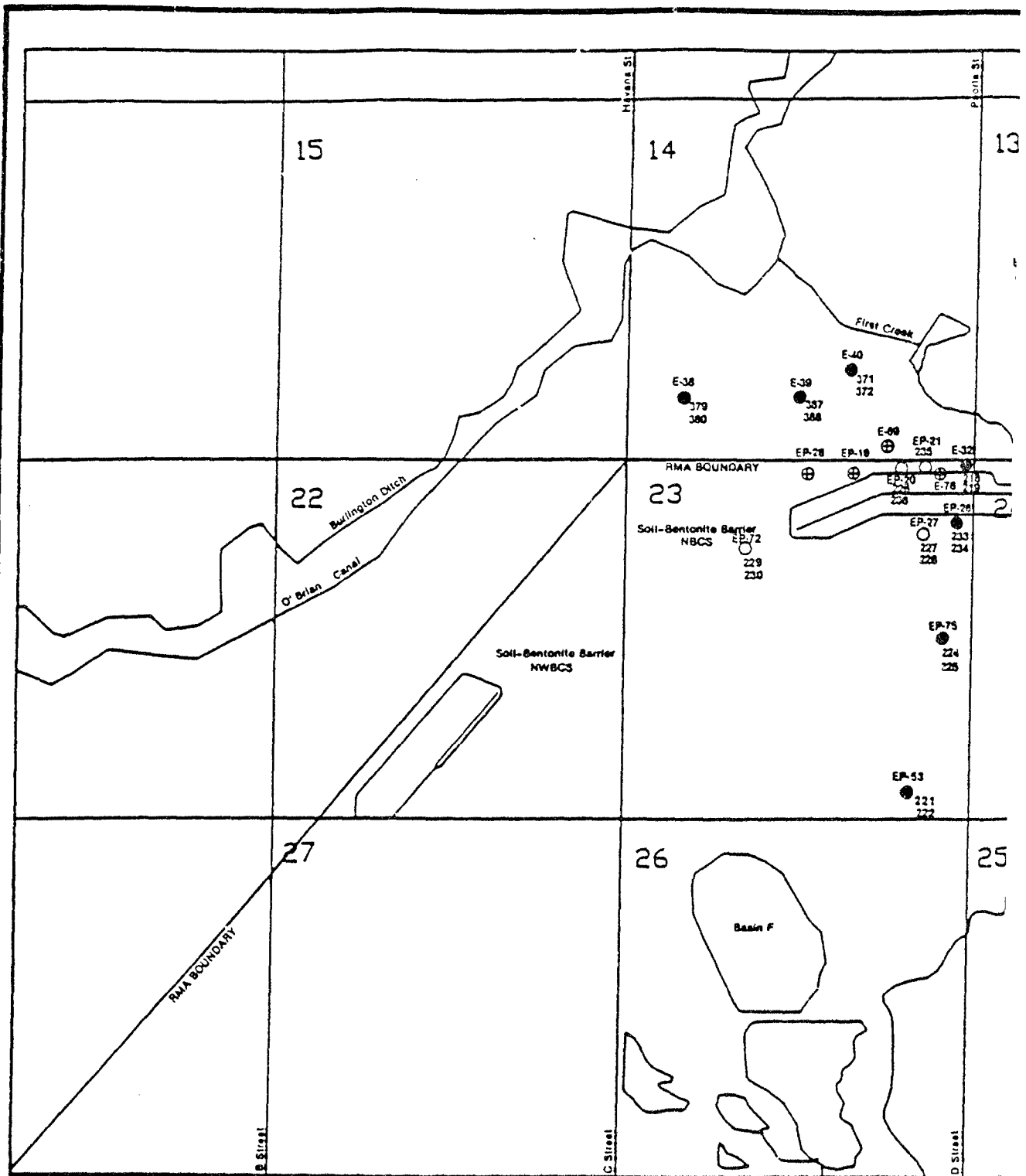
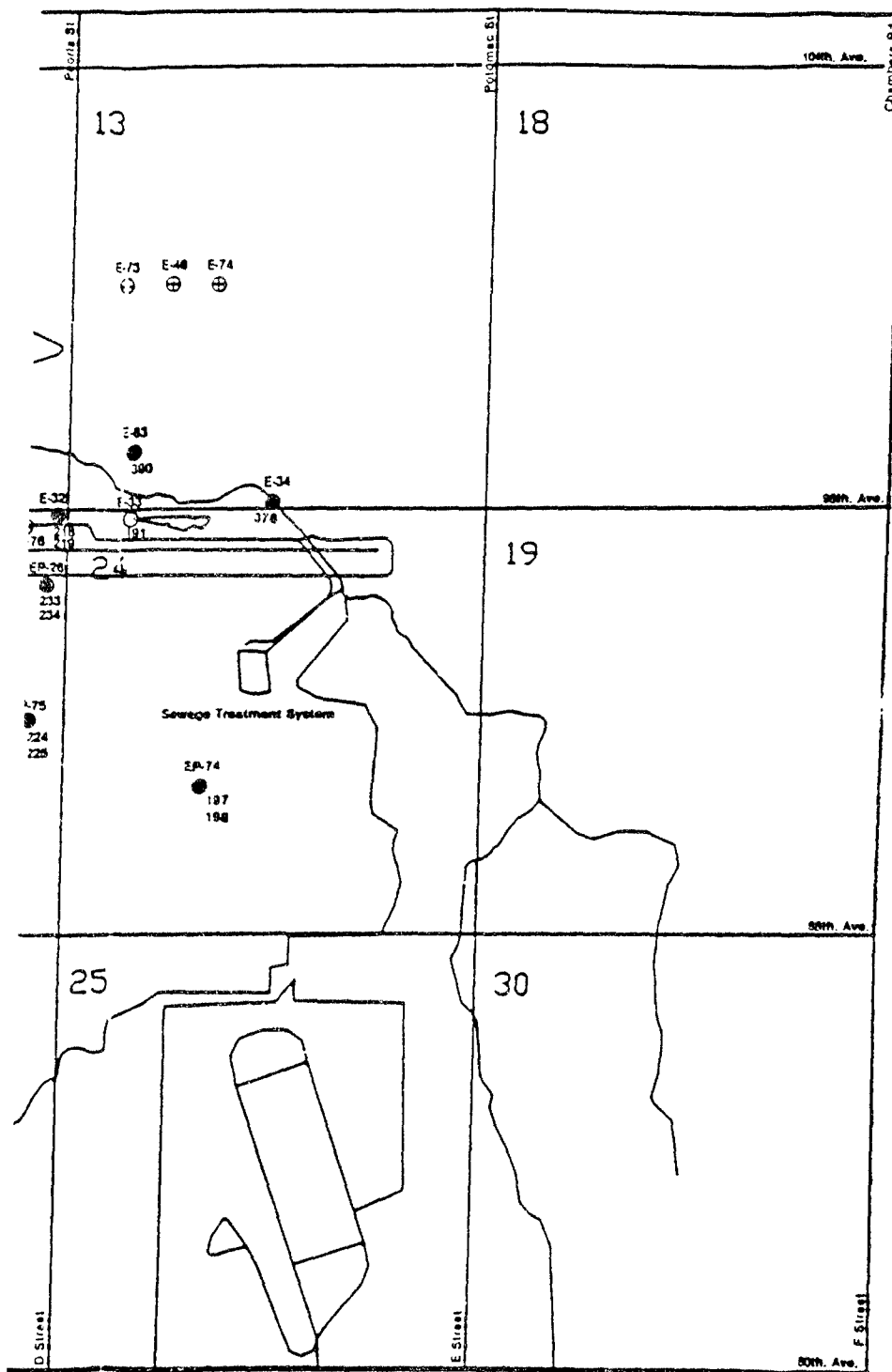


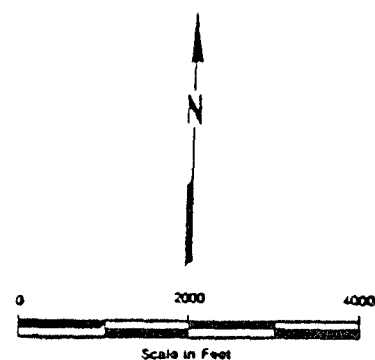
Figure 2.1-3
NEW DENVER SITES

SOURCE: ESE, 1988



EXPLANATION

- NWBCS NORTHWEST BOUNDARY CONTAINMENT SYSTEM
- NBCS NORTH BOUNDARY CONTAINMENT SYSTEM
- DENVER WELL SITE
- DENVER WELL(S) PAIRED WITH ALLUVIAL WELLS
- ⊕ DEEP BORING
- EP-9 SITE NUMBER
- 373 WELL NUMBER



Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland

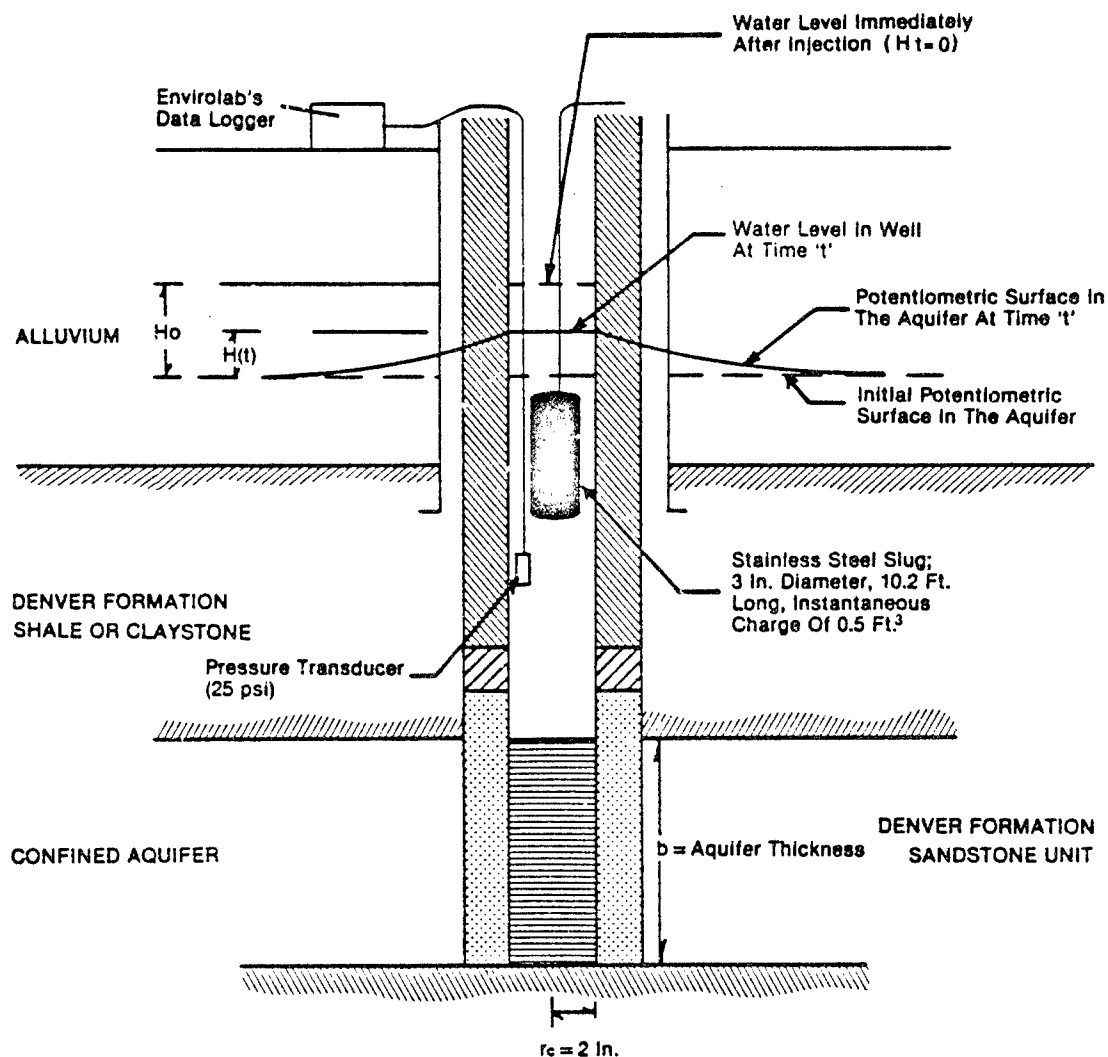


Figure 2.3-1
IDEALIZED DIAGRAM OF SLUG-IN AQUIFER
TEST (After Cooper et al, 1967)

SOURCE: ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

3.0 GEOLOGY

To facilitate the interpretation of hydrologic conditions, the extent of contamination, and the rate of contaminant transport in the vicinity of the NBCS and the NWBCS, a thorough understanding of the local geology (i.e., lithology, stratigraphy, and depositional environment) is essential. The geologic interpretation, as presented, progresses from a regional to a study area specific description. The geologic units of primary concern are the unconsolidated surficial deposits (alluvium) and the Denver Fm.

Characterization of the surficial and bedrock geology is based on information obtained from numerous sources and includes lithologic and electric well logs and reports from previous and ongoing investigations. A grid of detailed cross sections was constructed and used to illustrate the general distribution of surficial sediments, as well as detailed Denver Fm stratigraphy in the Task 25 area. This interpretation of Denver Fm stratigraphy was correlated across the study area and resulted in the definition of numerous hydrostratigraphic zones within the Denver Fm.

A data base of subsurface information was developed and used to track the correlations. The results and observations of previous and ongoing investigations, including studies by Morrison-Knudsen Engineers, Inc. (MKE) and RMA Tasks 36 and 44, are an integral part of the interpretations presented in this report. Other sources include May (1982, RIC#82295R01), May *et al.* (1983, RIC#83299R01), Lindvall (1971a, RIC#81352M039; 1971b, RIC#81352M022), MKE (1988), and Robson (1984).

3.1 GENERAL GEOLOGY OF THE RMA AREA

The topography at RMA consists of rolling hills, expansive areas of plains, and small enclosed basins. The maximum local topographic relief is approximately 220 ft. The elevation above mean sea level (msl) ranges from 5,340 ft at the southern boundary to

5,120 ft at the northern extent. The topographic surface slopes gently northwest towards the South Platte River at approximately 0.35 degrees.

RMA is located within the geologic province of the Denver Basin, a structural depression resulting from tectonic adjustments which occurred intermittently throughout time. The basin exhibits an elongate, north-south trending surface expression 300 miles long and 200 miles wide in north-central Colorado, Wyoming, and Nebraska. Mountains of the Front and Laramie Ranges bound the basin on the west; the Hartville Uplift and Chadron Arch on the north; and the Las Animas Arch and Apishipa Uplift on the south. Sedimentary strata composed of conglomerate, sandstone, shale, and limestone lithologies rest on the Precambrian basement and fill the synclinal structure. Strata range in age from Cambrian to Quaternary (Tweto, 1980).

RMA lies on a bedrock surface formed by the Late Cretaceous to early Tertiary Denver Fm. Quaternary alluvial and eolian deposits mantle the surface and obscure the Denver Fm over most of RMA. Regional dip is 0.5 degrees or less to the southeast.

The basin acquired its present configuration during the Late Cretaceous to Tertiary Laramide Orogeny. Regional uplift, mountain glaciation, and development of the present drainage system characterize the late Tertiary to recent history of RMA. The episodes caused extensive erosion which removed great thicknesses (up to 1,400 ft) of the Denver Fm and carved the paleochannels which underlie the surficial deposits on RMA (Costa and Bilodeau, 1982, RIC#82308R01).

Sediments present at the land surface at RMA consist of unconsolidated alluvial and eolian deposits of Quaternary age (Figure 3.1-1). The surficial material varies in thickness and is composed primarily of alluvial valley fill, fine-grained eolian sediments, and glacial outwash containing cobbles, boulders, and beds of volcanic ash in a matrix of sands, gravels, silts, and clays. Thicker deposits are found in

paleochannels eroded into the surface of the Denver Fm. The alluvial material commonly becomes more coarse at the base near the bedrock contact.

The Denver Fm underlying RMA consists of 250 to 400 ft of olive, bluish-gray, green-gray, and brown bentonitic clayshale and siltstone. It is interbedded with poor- to moderately-sorted, weakly lithified, tan to brown, fine- to medium-grained sandstone. The contact between the alluvium and Denver Fm is often marked by a weathered zone in the Denver Fm that may be up to 40-ft thick. Lignite beds and carbonaceous shales are common, as are volcanic fragments and tufaceous materials. Sandstones are mainly discontinuous to semicontinuous lenticular bodies which may be shoestring or sinuous in nature. These lenses, which represent the major flow pathways for Denver Fm ground water, are distributed within thick claystone sequences. These sandstones are poorly defined and often grade into the encompassing clay and shale. A shale claystone layer ranging from 75- to 200-ft thick, referred to as the "Buffer Zone", marks the base of the Denver Fm in the RMA area. Previous assessments indicate that the geology and hydrology is quite complex in the vicinity of RMA (Ertex, 1982, RIC#83013R01; May, 1982, RIC#82295R01).

3.2 QUATERNARY UNCONSOLIDATED SEDIMENTS

RMA is almost entirely covered with unconsolidated eolian and alluvial/fluvial deposits, some of which are glaciofluvial in nature. These sediments were deposited during the Pleistocene and Holocene epochs of the Quaternary period. Exposures of the underlying Cretaceous to Tertiary age Denver Fm bedrock occur only as outcrops on or near isolated topographic highs.

3.2.1 CHARACTERIZATION

Unconsolidated sediments as much as 100-ft thick overlie the bedrock in the vicinity of RMA (Lindvall, 1971b, RIC#81352M022). The alluvial deposits have been classified in the literature according to age, origin, and physical characteristics. These include, from oldest to youngest, the Verdos, Slocum, Louviers, Broadway, Piney Creek, and Post-Piney Creek. An eolian unit blankets underlying material over most

of RMA and is the predominant unit that occurs at ground surface in the Task 25 area. The alluvial deposits at RMA have been logged in soil borings using the Unified Soil Classification System (USCS), shown in Figure 3.2-1. The stratigraphic relationship between the units is illustrated in Figure 3.2-2.

An east-west cross section constructed through the north boundary of RMA (Figure 3.2-3) illustrates the general stratigraphic relationships between the alluvial and eolian units. This diagram illustrates that progressively younger sequences may occur at stratigraphically lower intervals than older sequences due to the deposition of younger sedimentary units in erosional valleys carved through previously deposited sedimentary horizons. The cross section also indicates that any of the alluvial units may occur in unconformable contact with the underlying bedrock surface. Recent work by MKE determined which alluvial material is in contact with bedrock at RMA (MKE, 1988). Alluvial units occurring in contact with bedrock in the Task 25 area are shown in Figure B-11.

3.2.2 DEPOSITIONAL HISTORY AND SEDIMENTARY CHARACTERISTICS OF ALLUVIAL UNITS

The Verdos is the oldest alluvial unit in the RMA area and consists of alluvial/fluvial reworked glacial sediments deposited in association with Kansan age glaciation. The majority of the Verdos in the RMA area was eroded post-depositionally during the Yarmouth interglacial period, and occurs in outcrops on the isolated bedrock highs of North Plants Hill in Section 25 and Henderson Hill near the east end of NBCS (Figure 3.1-1 and 3.2-3). Despite the fact that the Verdos Alluvium predates other younger Quaternary sediments, it is located at topographically higher elevations directly atop weathered bedrock highs. Remaining Verdos is 10- to 20-ft thick in the RMA area, and consists of light brown to reddish-brown, poorly-sorted, well-stratified, cobbly gravel with occasional clay, sand, and silt lenses.

Sediments of the Slocum unit were deposited in association with the Illinoisan glacial period that followed the Yarmouth interglacial period. The Slocum is generally 10- to

15-ft thick in the RMA area (Lindvall, 1971a, RIC#81352M039). MKE (1988) identified Younger and Older Slocum depositional sequences distinguished by differential terrace development. The Older Slocum is predominately poorly graded gravels and sands, with occasional "pea gravels" and silty clay intervals. The Younger Slocum is comprised of sands and gravels with a generally higher percentage of finer-grained constituents than the Older Slocum (MKE, 1988). Both the Younger and Older Slocum were deposited by fluvial sedimentary processes and generally become finer grained toward the top of the unit. In the Task 25 area, the Younger Slocum occurs in contact with the bedrock surface in northeastern portions of Section 22, and the Older Slocum directly overlies the bedrock surface in Sections 23, 24, and 26 (Figure B-11). The Slocum is overlain by a cover of eolian sands in the north central and northwest portions of RMA and does not outcrop in the Task 25 study area.

The Louviers was deposited in association with early Wisconsin glacial events. The Louviers consists of arkosic sands and gravels that are poorly graded and contain minor amounts of silts and clays. As with the Slocum, the Louviers is fluvial in origin. This unit may be up to 35-ft thick in the RMA area (Lindvall, 1971a, RIC#81352M039), but is generally 5- to 20-ft thick (MKE, 1988). The Louviers occurs in contact with the bedrock surface along western margins of the Task 25 study area (Figure B-11). This unit does not subcrop on RMA but does outcrop offpost along the South Platte River (Figure 3.1-1).

MKE identified channel fill that was interpreted to have been deposited following Louviers sedimentation. This channel fill generally consists of coarse gravels interbedded with clay and silt, though the extent of these stratigraphic sequences may be highly variable. This unit occurs in contact with the bedrock surface in the Basin A neck area of Section 26, in central portions of Section 27, and in the eastern portions of Sections 24 and 25 (Figure B-11), and was included with the Broadway Alluvium in Figures 3.1-1 and 3.2-2.

The Broadway Alluvium (Wisconsin Age) represents the flood plain deposits of the South Platte River (Figure 3.1-1). It outcrops offpost in a mile-wide terrace immediately east of the South Platte River. The Broadway Alluvium ranges in thickness to about 30 ft and consists of fine- to medium-grained arkosic sand and gravel, generally less than 1 inch in size, with scattered cobbles as large as 4 inches (Lindvall, 1971a, RIC#81352M039). The MKE (1988) interpretation includes material previously identified as Louviers by Lindvall (1971a, RIC#81352M039) in the Broadway Alluvium. As identified by MKE (1988), the Broadway occurs in contact with the bedrock surface in central portions of Section 27 in the Task 25 area (Figure B-11), but does not outcrop on RMA.

Loess was deposited in variable depths over the Broadway Alluvium during the late Pleistocene (Wisconsin) and early Holocene epochs (Figure 3.2-2). Loess is a yellowish-brown to light grayish-brown sandy silt (Lindvall, 1971a, RIC#81352M039) and comprises a unit that is generally less than 10-ft thick. The Loess unit does not occur in contact with the bedrock surface and does not outcrop on RMA.

The Eolian Sand unit was deposited during the Holocene epoch (Figure 3.2-2) and occurs at ground surface over the majority of RMA (Figure 3.1-1). This unit consists of very fine to fine silty sands, sandy silts, and clay. Generally 10- to 20-ft thick, the Eolian unit may be up to 50-ft thick where infilling of previously incised ravines occurred (MKE, 1988). The Eolian unit occurs in contact with the bedrock surface in the eastern portion of Section 27 and western half of Section 25 in the Task 25 study area (Figure B-11).

The Piney Creek Alluvium is the most recent sediment accumulation on RMA. This alluvium is fluvial in origin and commonly consists of 5- to 10-ft thick sequences of interbedded sands, silts, and clays with gravel channels at the base. Piney Creek deposition is found along First Creek, Second Creek, and in some southwestern sections on RMA (Figure 3.1-1). Post-Piney Creek Alluvium was also deposited in the area, but does not occur at RMA. The Post-Piney Creek Alluvium is the

predominantly fine-grained material that comprises the flood plain of the South Platte River (Figure 3.1-1).

3.3 BEDROCK SURFACE

The bedrock surface in the Task 25 study area has been characterized by describing the topography, the paleochannels, and the general physical characteristics. These three categories will be described in the following paragraphs.

3.3.1 TOPOGRAPHY

The topography of the Denver Fm at RMA has an overall regional downward slope to the northwest toward the South Platte River channel. The maximum elevations of the bedrock surface occur in the southeast quadrant of RMA. The area immediately northwest of RMA generally has the lowest bedrock elevations and the greatest amount of topographic relief as a result of the incision of tributary paleochannels.

Crossing RMA, in the central and north-central areas, there occurs a northeast-trending alignment of isolated bedrock highs. These highs include Rattlesnake Hill, North Plants Hill, and Henderson Hill, the latter which is near the north boundary of RMA. In the southern portion of Sections 23 and 24, the bedrock surface has very little topographic relief and slopes gently northward as shown in Figure B-10.

Bedrock elevations in this area range from 5,080 to 5,130 ft above msl. Immediately north of NBCS, near the line of NBCS recharge wells, the bedrock surface dips steeply north and northwest at a slope of approximately 5 percent.

3.3.2 PALEOCHANNELS

Paleochannels in the bedrock surface converge toward the NBCS. Figure 3.3-1 illustrates the configuration of paleochannels incising the bedrock surface. There is a paleochannel that approximately corresponds to the present location of First Creek which will be referred to as the First Creek paleochannel (FCP). FCP intersects the eastern extension of NBCS in the northeast quadrant of Section 24. After crossing under the RMA north boundary, FCP bifurcates, and a subsidiary paleochannel trends northward through the western half of Section 13. The dominant portion of the FCP

bend's sharply west, downgradient of this bifurcation, and then trends northwest through Sections 14 and 10 toward the South Platte River drainage. Two channels originate in the southern portions of Sections 23 and 24 and trend north and northeast, downslope toward the NBCS. These two paleochannels are tributary to the FCP. Although paleochannels exist in the vicinity of the NBCS, overall changes in bedrock surface elevation are relatively small. Only 100 ft of topographic relief is expressed in the bedrock surface in Sections 13, 14, 23, and 24 surrounding the NBCS.

In Sections 22 and 23, west of the FCP tributaries, is a relatively flat bedrock high area. A southeast to northwest trending paleochannel crosses under the RMA boundary in the vicinity of the NWBCS in Section 22. This major paleochannel will be referred to as the Northwest Boundary paleochannel (NWBP). Onpost, this paleochannel trends directly southeast to northwest but offpost, as it crosses Section 21, it begins to trend in a northerly direction. There are several smaller channels tributary to this main channel in Sections 22 and 27. A relatively subtle channel on the western side of Section 27 trends directly north within the Task 25 study area. This channel appears to be a tributary to the main paleochannel along the NWBCS. The area southwest of the NWBP is a flat area of relatively high bedrock elevations. The paleochannels in the vicinity of the NWBCS are subtle, and do not cause great variations in bedrock surface elevation. In the area surrounding the NWBCS, the maximum topographic relief is less than 50 ft.

3.3.3 GENERAL PHYSICAL CHARACTERISTICS

The surface of the bedrock is deeply weathered. A depositional hiatus following lithification of the Denver Fm left the surface exposed to erosional processes. This is evidenced by erosion that has created a bedrock surface that slopes topographically toward the northwest, while the regional dip of the Denver Fm is gently to the southeast. Weathering of the surface has left upper portions of the fine-grained Denver Fm disaggregated. As such, it is often very difficult to pinpoint the precise contact between the Denver Fm and the overlying, unconsolidated alluvial sediments

based on size and friability only. Changes in texture, color, composition, and mineralogy are required to discern this interface.

3.4 DENVER FORMATION

In addition to the surficial sediments, the other geologic unit of primary concern in the Task 25 study area is the Denver Fm. In this report, the Denver Fm is characterized through a description of its depositional environment, the resulting sandstone morphologies, and a stratigraphic correlation of sandstone units within the formation. This discussion is limited to hydrostratigraphic zones that act as the primary pathways for ground water movement in the formation and that subcrop within the Task 25 study area. The geologic interpretation has been conducted primarily through the preparation and assessment of geologic cross sections, structure contour maps of the base of the hydrostratigraphic zones, net sand isopach maps for each zone, and a Task 25 study area subcrop map.

3.4.1 DATA PRESENTATION

The stratigraphic correlations presented and the resulting interpretation of Denver Fm geology is based upon numerous cross sections and maps that were constructed under Tasks 25, 36, 39, and 44. What follows is a description of the methodology used in preparation of these work products.

Cross Sections

The initial characterization of the Denver Fm geology included an assessment of available lithologic and geophysical logs of all existing and newly installed boreholes in the Task 25 study area. A grid of 22 detailed cross sections was constructed upgradient of the NWBCS that included all of the Denver Fm boreholes in the area. The borehole locations were projected onto the cross section lines. The density of cross section lines ensured that wells were generally projected less than 300 ft. In Sections 22 and 23, between the boundary containment systems where Denver Fm data are limited, some boreholes were projected over longer distances. These

boreholes were used to fill data gaps but the correlations in this area were not given as much weight as those in areas of greater data density.

Eleven of the cross sections were constructed in a northeast to southwest direction along the general direction of strike. An equal number of cross sections were constructed parallel to the regional dip in a northwest to southeast direction. Eight of these cross sections - four dip and four strike sections - are included in this report (Figure B-1). The sections are illustrated in Figures B-2 through B-9 and represent the interpretations presented in this report.

A grid of 30 north to south and east to west cross sections were constructed under Task 36 in the vicinity of the NBCS. There is a greater density of Denver Fm boreholes near the NBCS and, therefore, these cross sections are more detailed in nature. These cross sections are presented in the Task 36 Report (ESE, 1989a, RIC#89103R01), and because they are located within the Task 25 study area, they are an integral part of the stratigraphic correlations presented in this report. These cross sections were tied to the NWBCS cross sections by common boreholes. Due to the greater density of data in the vicinity of the NBCS, a more precise definition of the channel and flood basin characteristics of the different hydrostratigraphic zones was possible in this area. For this reason the stratigraphic correlations were initially made in the vicinity of the NBCS and then carried southwest to the NWBCS area. However, due to the orientation of the Denver Fm units and the erosional surface, many of the sandstone units identified near the NBCS are eroded in the vicinity of the NWBCS.

The hydrostratigraphic zones were defined on the basis of their base elevations, top elevations, and general configuration. In some places the zones have significant thicknesses of clay shales separating them, and in many places, the zones consist of thick sandstone layers. In many cases a thick channel sand and associated flood basin sands and clayshales were defined and correlated to another channel sand in the same stratigraphic horizon. In the vicinity of the NBCS, where the density of boreholes is

greatest, the lithology indicates a configuration of many channels vertically accreted. In other areas where borehole data are limited, some likely channel sands have been identified but are difficult to define with any precision.

Structure Contour and Isopach Maps

A structure contour map was constructed for the base and top of each hydrostratigraphic zone. This permitted a precise definition of the zone and ensured that the zones were not being cross correlated. The contour maps of the base of each zone are presented in Figures B-13 to B-22.

A net sand isopach map was constructed for each hydrostratigraphic zone. The thickness of each zone from top to bottom of sand was measured from the logs, and the thickness of interlayered clayshale stringers, if any, was subtracted from the total. The values were posted on a map and contoured to permit the definition of thicker sandstone within the zone. These thicker sandstone units probably represent corridors of greater flow potential within the hydrostratigraphic zone. In areas of lower borehole density, areas of thicker sandstone are apparent but are more difficult to delineate.

Subcrop Map

A Denver Fm subcrop map is shown in Figure B-12. This subcrop map was generated by plotting the location of the intersection of the top and bottom surface of each hydrostratigraphic zone with the bedrock surface. The subcrop areas were defined using the grid of cross sections. The thicknesses of the zones were projected onto the bedrock contour map at an angle consistent with the regional dip of less than 0.5 degrees. The subcrop areas presented in Figure B-12 represent associated units of sandstones, siltstones, and claystones, which comprise the hydrostratigraphic zones. The inferred subcrop areas of the lignite units are also represented. Lignite A through hydrostratigraphic zone 4 subcrop successively across the study area from south to north.

3.4.2 DEPOSITIONAL ENVIRONMENT

The nearshore-deltaic sediments of the late Cretaceous age Fox Hills/Laramie Fm were deposited in the Denver Basin area prior to a widespread tectonic mountain building event called the Laramide Orogeny. At the initiation of the Laramide Orogeny, 67 million years ago, most of the western United States was covered by marine waters. As the Colorado Front Range was uplifted and the Denver Basin downwarped, the inland sea retreated southward. The Late Cretaceous age sedimentary formations underlying the Denver Fm have sedimentary facies that indicate a transition from tectonic uplift to erosion and deposition. The lithologies comprising the Denver Fm indicate that natural processes were still eroding the relatively new Rocky Mountain Front Range (Tweto, 1980; Soister, 1978).

The relative abundance of fine-grained lithologies comprising the Denver Fm and lack of marine fossil material indicates that the formation was deposited predominantly in low-energy, non-marine environments. Low-energy fluvial depositional environments commonly include low-gradient meandering streams with bogs, floodbasins, and calm-water scenarios. These environments are often located far from upland areas contributing coarse clastic input to the depositional regime. This type of depositional environment is termed a distal alluvial plain depositional setting. Deposition is controlled by a combination of lateral and vertical aggradation by meandering streams and results in a complex interrelationship of point-bar sands, channel-fill sands, and flood basin sediments, which include flood basin sands, back swamp organic clays, and clay/lignite intervals. In detail, this internal stratigraphy is very complex, and correlation of individual units can be difficult. However, when evaluated using the concept of litho- or hydrostratigraphic zones, correlation between sand units over distances of up to the width of the meander belt is possible (Walker and Cant, 1984). Figure 3.4-1a illustrates a depositional scenario for the Denver Fm at RMA. During the Early Paleocene epoch, as the Rocky Mountain Front Range rose, material was eroded from the uplifted areas and deposited along the east flank of the Front Range in a distal alluvial plain environment. Basin subsidence in this setting led to repeated sequences of discontinuous stratigraphic units.

Figure 3.4-1b portrays an example of lateral sand accretion in which a stream meandering across a floodplain deposits units of varying morphology and lithology. In this depositional environment, point-bar sands accrete laterally across the floodplain as the sinuosity of the meander belt increases. High-water episodes in this setting can lead to breaching of the natural levee and deposition of locally continuous, sheetlike deposits of silts, clays, and sands known as flood basin deposits. The vertical succession and lateral coalescence of these flood basin deposits results in an interbedded, stacked sequence of fine-grained sediments similar to those documented at RMA. Through time, this complex depositional process will produce vertically stacked and laterally accreted thick channel sands, with associated laterally discontinuous sandstones, siltstones, and claystones. The geometry of individual shoestring-like sand units and stacked sequences of fine-grained sediments observed at RMA supports the applicability of this depositional model.

Meander belts are also conducive to the deposition of discontinuous carbonaceous units in abandoned stream channels and oxbow lakes.

Figure 3.4-1c illustrates how a low-gradient meander belt can result in a vertical accretion of a sequence of shoestring-like sand bodies surrounded by siltstones, claystones, and lignites. These morphologies have been observed on both a local and regional scale at RMA.

An understanding of the depositional environments and resultant morphologies of the Denver Fm sandstone units is fundamental to understanding ground-water flow patterns. Ground water moves from areas of high hydraulic head to areas of low hydraulic head predominantly through materials of highest hydraulic conductivity. At RMA, the more permeable sediments of the Denver Fm are the sands of channel and flood basin deposits.

3.4.3 STRATIGRAPHIC CORRELATION WITHIN THE DENVER FM

Stratigraphically correlating individual sandstone units for moderate to long distances across RMA is complicated by the non-depositional and/or erosional truncation of individual units. The Denver Fm at RMA has a regional strike from southwest to northeast and an average regional southeasterly dip of less than one degree. A Denver Fm sandstone unit that may subcrop and lie in direct contact with the alluvium in the northwest portion of RMA will occur, or its stratigraphic equivalent will occur, at greater depth toward the southeast (May *et al.*, 1980, RIC#81266R48).

Geologic studies at RMA have identified numerous hydrostratigraphic zones in the Denver Fm which include one or more individual sandstone units. These hydrostratigraphic zones have been found to be mappable across RMA. Figure 3.4-2 illustrates the generalized reconstruction of the Denver Fm stratigraphic column at RMA. A nomenclature scheme was based on the occurrence of a stratigraphic marker bed. This marker bed is a thick, fairly laterally continuous lignitic interval identified as lignite A (LA). Lignite intervals are named LB, LC, and LD downsection from this marker. Using LA as the marker bed, hydrostratigraphic zones were assigned a number based on proximity to the marker bed, with zones immediately below LA named the 1u, underlain by zones 1, 2, 3, and 4. Hydrostratigraphic zones above the marker bed were assigned a letter designation based on proximity to the LA, with the A zone immediately above the marker bed. A volcanoclastic interval (VC) and associated clay-rich stratigraphically equivalent zone (VCE) were also identified. Lignite A is equivalent to MKE Zone 7500. Hydrostratigraphic zones 1u through 4 correspond to MKE units 7100 through 7400 (MKE, 1988).

Each hydrostratigraphic zone consists of fluvial channel sands and associated flood basin deposits. The intervals between these zones generally consist of 0 to 30 ft of clay rich sediment. Some of the zones are also separated vertically by somewhat discontinuous, but correlatable, lignitic intervals. These intervals may indicate a cessation of localized fluvial deposition and subsequent development of quiet water, organic-rich bogs. Characterization of zones 1u through 4 are presented in this report

because Denver Fm sandstones associated with these zones subcrop in the Task 25 study area. The lignites subcrop in the southernmost Task 25 study area.

3.4.4 CHARACTERIZATION AND DEFINITION OF THE DENVER FM SANDSTONES

Underlying the northern sections of RMA, the Denver Fm generally consists of carbonaceous clayshales, claystones, and siltstones interbedded with lenticular sandstone units. The Denver Fm sandstone units are micaceous, locally lignitic, and contain dark-colored minerals such as augite and hornblende. The sandstone units are generally unconsolidated, although locally they may be well-cemented with calcium carbonate and silica. The sandstones are considered the principal water bearing units in the Denver Fm. A summary of the depositional history, occurrence, and extent of hydrostratigraphic zones 1u through 4 are presented below in stratigraphic order from oldest to youngest, followed by descriptions of lignitic units presented in a parallel sequence for the Task 25 study area.

To accomplish the correlation of Denver Fm hydrostratigraphic zones in the Task 25 study area, 22 geologic cross sections were constructed. These cross sections were tied by common boreholes to 30 cross sections constructed in the vicinity of the NBCS under Task 36. Figure B-1 is a location map for the eight cross sections presented in this report. The cross sections are oriented southwest to northeast along strike, and northwest to southeast in the dip direction. Eight of these cross sections are presented in Appendix B as Figures B-2 through B-9.

Hydrostratigraphic Zone 4

Sandstones in hydrostratigraphic zone 4 have been described as quartzitic. They are green grey to dark grey (Munsell 5Y4/1) in color, generally fine- to medium-grained, often uncemented, calcareous, and carbonaceous. Zone 4 is often described as massive, as in the core from Well Site 23225 on cross section 50.0 and Well Site 23230 on cross section 26.5, but it may also contain thinly bedded clay laminae, as in the core from Well Sites 37388 and 23222 on cross section 50.0.

Structure contour maps of the base of the zone and net sand thickness for zone 4 are presented in Figures B-13 and B-14. The base elevation of zone 4 ranges from approximately 5,000 ft msl in Section 26 to 5,070 ft msl offpost in Section 22. There are areas of relatively low elevation under the western end of the NBCS and on the northeastern end of the NWBCS, trending generally northwest from Section 26 through 22. These low elevation trends may represent areas of stream scour, but their significance is unclear due to the limited number of data points. There is a sandstone under the eastern end of the NBCS in Section 24 with thicknesses of over 20 ft. There is also a thick sandstone lens underlying much of Section 23, as illustrated on the net sand thickness map. Underlying the NWBCS, the sandstone thickness varies from less than 5 ft to more than 15 ft, but the limited data makes definition of sand morphology unclear.

Most of the boreholes completed in zone 4 are located in the area of subcrop along the western and northern portions of RMA. The sandstone distribution is sheet-like in Sections 22, 23, and 25. The sandstones in this zone may be over 30-ft thick, however thicker areas generally contain interbedded clays. The distribution of sandstone and other lithologic data indicate that zone 4 may be a flood basin deposit over most of the Task 25 study area.

Dip section 50.0 follows a north-northwest trending, relatively thicker sandstone in zone 4. Zone 4 is present in the borehole at Well Site 25020 where it is approximately 30-ft thick. The total thickness is unknown since the borehole does not completely penetrate zone 4. Northwest, along the line of the cross section, zone 4 is approximately 20-ft thick, as exhibited by the core for Well Sites 23225 and 23234. In the vicinity of Well Site 37388, it increases to about 30 ft.

Strike cross section NWB 26.5 illustrates the rapid change in sandstone morphology for zone 4 from the locus of sand deposition in the channel to the flood basin environment. Zone 4 is present in a relatively thick unit of 30 to 40 ft in the core for

Well Sites 23210 and borehole 995. Both of these boreholes are in the main sand channel trend. However, southward along the line of the section, zone 4 thins rapidly to approximately 10-ft thick in the core for Well Site 23191. Zone 4 also illustrates the discontinuous nature of fluvial deposition in a meander belt setting as seen in the central portion of cross section 26.5.

The subcrop area for zone 4 occurs onpost in Sections 22 and 27 and trends northeast to southwest along the direction of strike. The areal extent of the subcrop area for zone 4 is based on projection of sandstone thicknesses from the cross sections updip to the intersection with the bedrock surface. Based on the available information, the width of the subcrop cannot be defined with any precision.

Hydrostratigraphic Zone 3

The sandstone intervals in zone 3 are described as quartz sandstones that are very fine- to medium-grained. In some areas the sand is silty with numerous claystone layers, as evidenced by the core from Well Site 26147 on cross section 0.0, from Well Site 37388 on cross section 50.0, and from Well Site 23230 on cross section 26.5. In general, the sandstone in this zone is greenish grey to dark grey (Munsell 5Y4/1) in color, moderately- to poorly-sorted, and poorly cemented to uncemented. There is some evidence of cross bedding (Borehole 26147, cross section 26.5). This zone includes greenish clayshale layers that are described as hard, blocky, and crumbly.

Zone 3 was deposited on top of zone 4. In some areas, sandstones are separated by a substantial shale interval and in other areas, relatively thick sandstones are superimposed. Data are sparse for zone 3 except under the NBCS. Trends indicate several thick sand bodies that are oriented primarily in a northeast to southwest direction under the northern half of Sections 23 and 24.

Structure contour maps of the base of zone 3 and net sand thickness for the zone are presented in Figures B-15 and B-16. Elevations of the base of the zone range from 5,055 ft msl in Section 30 to 5,106 ft msl in Section 22. There is a broad area of

relatively low elevations under the NBCS. The deposits under the southern half of Sections 23 and 24 are clay rich and are probably flood basin deposits. In the vicinity of the NWBCS, the sandstone units appear to be relatively thin, with thicknesses less than 10 ft; however, data are sparse in this area and variations in sandstone thickness are not well defined. Only a few offpost wells are completed through zone 3, and its configuration offpost is, therefore, not well defined.

Dip cross section 50.0 crosses a thick sandstone lens in Section 24 and illustrates a channel-like morphology. The lithologic log from the borehole at Well Site 24198 indicates that zone 3 is up to 35-ft thick in the center of the sand trend. Due to a 2,150-ft projection from the south, Borehole 23223 does not contain a zone 3 interval. However, zone 3 occurs in the core from Well Site 23224 and is 20-ft thick. Along the line of the section to the west, zone 3 remains consistent in thickness. The line of the cross section follows the trend of sandstone deposition in Section 23.

Strike cross section 26.5 illustrates a flood basin morphology of zone 3 in the strike direction. The sand is approximately 30-ft thick in the core from Well Site 23209 and 23224. Crossing out of the main channel trend, zone 3 takes on the morphology of flood basin sands as illustrated in the boreholes from wells 23193 and 23198 where it is approximately 20- to 25-ft thick and sheet-like. Zone 3 is not present in the borehole from well 23185 due to an 800-ft projection from the west. Zone 3 is present in the lithologic log from Well Site 23415 and does not occur in the remainder of the section.

The subcrop area of hydrostratigraphic zone 3 is a northeast to southwest trending belt 500- to 3,000-ft wide under the central portions of Sections 27 and 22. The subcrop trends in a more northeasterly direction under the southern portion of Section 14 and central Section 13, downgradient of the NBCS. Due to the limited number of boreholes, much of the subcrop area for zone 3 is projected updip using the cross sections and the configuration of the bedrock surface.

Hydrostratigraphic Zone 2

The descriptions of sandstones in zone 2 are quite varied. Intervals generally consist of quartz sandstones that are fine- to medium-grained, massive to thinly bedded with a friable texture. They may be silty with claystone layers interbedded with the thinner sandstones. There is some evidence to indicate localized graded bedding as evidenced in the core from Well Site 23221 on cross section 27.2 and Well Site 26141 on cross section 71.1. The sand is green grey (Munsell 5Y5/2) to grey in color, often uncemented, and contains occasional organic and micaceous material, with muscovite as the dominant mica species. The sandstones are occasionally described as oxidized, evidenced by the core from Well Sites 23230 and 37388 on cross section 50.0.

Zone 2 was deposited on top of zone 3. In some areas sandstones in zones 1 and 2 are separated by a substantial clayshale interval, while in other areas thick sandstones from the two zones are superimposed. There is a sizeable data base available to characterize hydrostratigraphic zone 2.

Structure contour maps of the base of hydrostratigraphic zone 2 and net sand thickness for the zone are presented in Figures B-17 and B-18. The base elevations of this zone range from approximately 5,070 ft msl underlying Section 30 to 5,120 ft msl underlying Section 26. Broad areas of high elevations occur under the central part of Section 26 and the northwest quarter of Section 25.

A sandstone up to 50 ft thick occurs under the southern half of Section 23 and the western portion of Section 26. This sandstone trends north to south in Section 26 and then shifts to a northwest orientation under Section 23. This sandstone will be referred to as the western channel in zone 2. Sands in the vicinity of the NBCS are less laterally continuous and are characterized by thinner (4 to 20 ft), more clay rich, flood basin sandstones. Isolated thick sandstones under Section 25 may indicate additional channel deposition, but lack of data in this area precludes further evaluation. Zone 2 is the uppermost zone underlying the NBCS, but appears to be eroded completely under the NWBCS.

Zone 2 exhibits flood basin characteristics under most of the Task 25 area. The northernmost thick sandstone, however, illustrates a more channel-like morphology. Dip cross section 50.0 illustrates the uppermost channel and is oriented along the channel trend. The borehole at Well Sites 25013 and 25012 indicate a bifurcated character of two sand stringers which coalesce into one sandstone unit to the west near Well Site 25019. Westward along the line of the section, zone 2 thickens across the channel trend in Well Sites 23222 and 23224, where it is approximately 30 ft thick. Zone 2 thins along the line of the section past the 0.0 tie line and subcrops offpost of RMA between Well Sites 37388 and 37379.

Strike cross section 71.1 follows the northerly trend of the western sand channel. Zone 2 in this section displays a consistent thickness of up to 50 ft in Well Sites 26140, 26063, and 36037.

Strike cross section 26.5 displays a cross section through the western sand lens. This section illustrates the very complex interrelationship of the sand stringers that make up the majority of zone 2 in the Task 25 area. In the core from Well Site 23224, zone 2 consists of four coalesced stringer sands that vary from 15-ft to about 5-ft thick and are separated by shale interbeds. Along the line of the section to the south, zone 2 exhibits an interfingering morphology of stringer sandstones related to the thick sands in Section 25.

The subcrop area for zone 2 in the Task 25 area is a sinuous belt approximately 2,000- to 6,000-ft wide, oriented in the direction of strike (Figure B-12). The subcrop zone trends northeast under Sections 27 and 22, and the northwest quarter of Section 23. Where the bedrock topography has less relief under the eastern portion of Section 23 and northwestern quarter of Section 24, the area of subcrop widens and covers a broad area of the bedrock surface. Zone 2 is completely eroded within one half mile north of the NBCS.

Hydrostratigraphic Zone 1

The sandstones within hydrostratigraphic zone 1 have been described as quartz sandstones that are very fine- to medium-grained. They are locally silty and are poorly-sorted to well-sorted. The sandstones in this zone display wide variations in the amount of cement present and often exhibit oxidized horizons, as evidenced by the lithologic log from Well Site 25009 on cross section 27.2, and the borings at Sites 26128 and 26141 on cross section 71.1. They are generally light grey or yellow to yellowish brown (Munsell 10Y5/8 to 6/8) in color and are locally micaceous with muscovite as the dominant mica species. The thicker sandstones in zone 1 are massive and well sorted compared to the thinner sandstones which occasionally exhibit a fine bedding structure.

Numerous data were available to assess sand occurrence in the north central portion of RMA. The sediments of zone 1 were deposited on top of zone 2. In many areas, the downcutting relationship between zones 1 and 2 superimposes thick sandstones, and in some areas, the two zones are separated by a substantial clayshale interval. Structure contour maps of the base of zone 1 and net sand thickness are presented in Figures B-19 and B-20. The base elevations of this zone range from 5,110 ft above msl in Section 30 to 5,155 ft above msl in Sections 26 and 24. Channel type sands 30- to 50-ft thick are present under the western margin of Section 25 and continue to the south. Clay- and silt-rich sands occur under the central portion of Section 25, indicating the flood basin deposits described in Section 3.4.2. Most of the thinner, finer-grained sediments encountered along channel margins may also be attributed to flood basin deposits. Zone 1 contains fewer clay-rich intervals than zones 2 through 4. Thick sandstones which occur under Section 30 may indicate the presence of channels, but lack of data makes assessment of lateral continuity difficult.

Zone 1 is eroded from under Sections 22 and 23, with the exception of some minor remnants in the southern portion of Section 23. It is eroded under Section 24, with the exception of the northeastern quarter, under the eastern extent of the NBCS.

Cross section 71.1 illustrates the thick channel-like morphology of the sandstones in a section perpendicular to the trend of a thick sand lens in the northeast quarter of Section 26. Erosion has greatly modified the appearance of zone 1 in the northeast. In Borehole 25003, zone 1 is approximately 5-ft thick and is in a subcrop position with the overlying alluvium. Nearly 800 ft along the section line to the south at Well Site 26123, the sand increases to 20 ft in thickness. At Well Site 26051, over 1,500 ft to the south along the section, sand increases to over 40 ft in thickness. Sand morphology is consistent with accreted sands of a channel. Zone 1 stays relatively consistent at 30- to 40-ft thick for approximately 2,000 ft along the section. The zone exhibits a flood basin morphology by Borehole 26060, where it is approximately 10-ft thick. Zone 1 maintains this thickness and morphology until pinching out a few hundred feet south of Borehole 36038.

Cross section NWB 0.0, constructed perpendicular to a main channel trend, illustrates the manner in which zone 1 thins and displays a flood basin morphology away from the channel. South of the Task 25 area, zone 1 is approximately 20-ft thick at Well Site 36112 increasing to approximately 30 ft thick in Well Site 26127. Approximately 800 ft west of Borehole 26127, zone 1 subcrops as a relatively thin (10-ft thick) "blanket" near Basin F and is eroded just west of the basin.

The subcrop of zone 1 is represented by a broad area approximately 2,000- to 7,000-ft wide in Sections 27, 26, 25, 24, 23, and 19. A broad, relatively flat area in the bedrock surface under Sections 23 and 26 allows the extensive exposure of zone 1 in this area.

Hydrostratigraphic Zone 1u

Descriptions of zone 1u indicate that the interval consists of fine- to medium-grained sandstones. This zone is moderately- to poorly-sorted, and the sands may locally contain silts and clays as evidenced by the borehole at Site 25009 on cross section 27.2. Zone 1u is generally well cemented and light green grey to olive grey (Munsell 5Y9/2) in color. This zone may contain lenses of clayshale and silt and may be

massive or thinly bedded. Clay intervals within the zone are thinly bedded, hard to moderately hard, grey to dark grey in color, with a blocky texture.

Zone 1u was deposited on top of zone 1 and is present in boreholes primarily in the central portion of RMA. Structure contour maps of the base of the sand and net sand contour maps are presented in Figures B-21 and B-22. Elevations in the Task 25 study area range from 5,150 to 5,170 ft above msl. There is a low area in the base of the sand zone representing an erosional channel trending northeast through the southwest quarter of Section 25. Sands in this area are over 10-ft thick. Thicker channel sands occur south of the Task 25 study area. The sand is eroded completely under Sections 22, 23, and 24, in the area of the NBCS.

Zone 1u has a limited distribution in the Task 25 area due to spotty deposition and/or erosion. The zone 1u net isopach map defines a thick sand lens with a channel morphology in the central and mid-central part of Section 35 trending almost due northwest. Dip cross sections NWB 0.0 and NWB -18.3 illustrate the extremely variable morphology of the unit.

On cross section NWB 0.0, zone 1u is identified in Well Site 26113. It occurs beneath lignite A (LA) and is approximately 10-ft thick. The sand has a stringer-like character of consistent thickness until it pinches out along the section in the vicinity of Well Site 26085. This stringer-like character is most consistent with a flood basin origin proximal to a channel trend.

In cross section -18.3, zone 1u has a more channel-like character, reaching a thickness of approximately 28 ft in Well Site 35080 where it is also in a subcrop position with the overlying alluvium. Westward along the line of the cross section, the zone 1u stays consistently thick as seen in Well Site 26096. Seven hundred ft west of Well Site 26096, zone 1u pinches out updip along the line of the cross section.

There is an erosional remnant located on the elevational high under the northeast quarter of Section 24. The 1u zone is generally thinner than deeper sand zones and contains occasional beds of clayshale and silt.

In the Task 25 study area, the subcrop of sand zone 1u is a sinuous belt approximately 500- to 5,000-ft wide, trending northeast to southwest through Sections 25 and 26. This zone is not of major significance to the Task 25 study area because it subcrops so far to the south.

Lignitic Intervals

The lignitic intervals consist of organic coals interbedded with black organic and grey shales, including occasional silty and sandy seams. The shales are highly variable in terms of hardness, and the thin, highly lignitic intervals exhibit more fracturing than clay rich intervals.

Lignitic zones may occur between zones 1u, 1, 2, 3, and 4. These carbonaceous zones are somewhat discontinuous but correlatable. The environments of deposition for these units are extensive, shallow, freshwater marshes and swamps. The variation in lignite thickness may be due to variation in deposition or erosion of the units.

Lignite A (LA) occurs between the A and 1u zones and is used as the principal marker bed at RMA. Where the 1u is absent, it occurs between the A and 1 zones. This unit is primarily lignite but also contains some carbonaceous shale. The approximate thickness of LA varies from 2 to 11 ft, with an average of 6 ft.

Lignite B (LB) occurs between zones 1u and 1 and is described as a lignite with lateral variations to lignitic carbonaceous organic shale and black shale. The approximate thickness of this unit varies between 0.5 to 12 ft, with an average of 5 ft.

Lignite C (LC) occurs between zones 1 and 2 and is predominantly a lignite with some lateral facies variation to an organic shale. This lignite has approximate thicknesses of 1 to 13 ft, with an average of 5 ft.

Lignite D (LD) is a lignite to organic shale horizon that occurs between zones 2 and 3. The approximate thickness of this lignite varies between 0.5 and 13 ft, with an average of 3 ft.

Additional lignitic zones have been identified, but data is sparse and the use of these zones as stratigraphic markers appears to be limited (MKE, 1988).

3.4.5 CONCEPTUAL GEOLOGIC MODEL

The Denver Fm at RMA has been subdivided into a group of hydrostratigraphic zones which may be described as sand-rich zones. These hydrostratigraphic zones have been correlated across RMA based on an interpretation of fluvial facies. In addition to these zones, a vertical series of lignites and a volcanoclastic horizon have been identified and correlated at RMA. The zones that subcrop in the Task 25 study area are described in detail in this report. These include zones 1u, 1, 2, 3, and 4. In addition, the lignitic intervals subcrop in the study area and are also included.

A meaningful approach to conceptualizing the distribution and relationship of sediments within a formation is to define the sedimentary environment.

The sedimentary environment may then be reduced to a group of subenvironments which have a complex interrelationship.

The Denver Fm was deposited on an upper alluvial plain proximal to the Front Range uplift during the Late Cretaceous to early Paleocene periods. The sediments within the Denver Fm indicate a fluvial depositional environment.

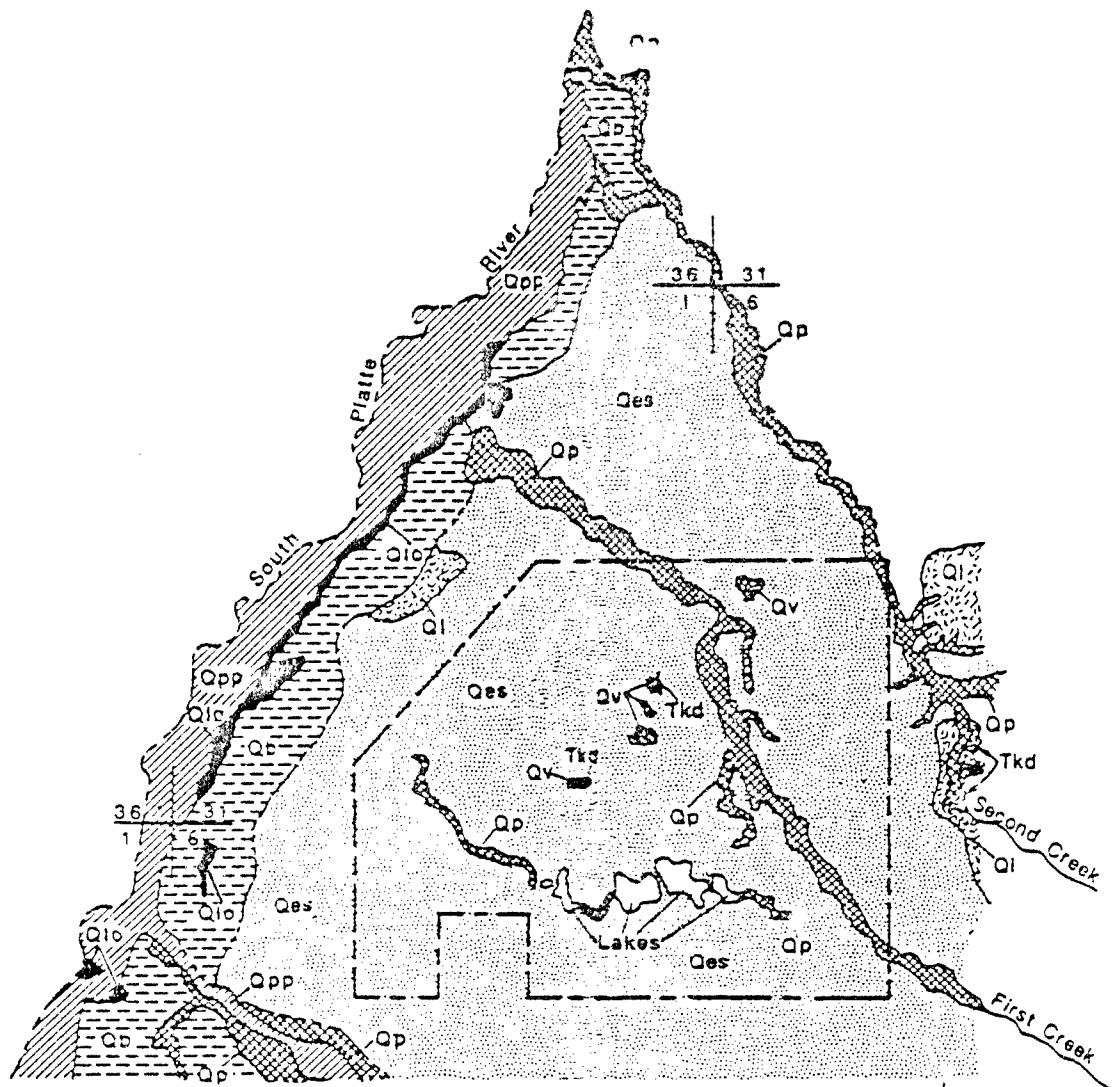
A variety of fluvial systems can form depending on the stream gradient and the rate and grain size of sediment influx. These range from low sinuosity braided streams

which carry coarse sediments to high sinuosity meandering streams which generally transport finer-grained sediments (Morse, 1979).

The depositional units of braided and meandering streams vary considerably in lateral continuity. Braided streams are characterized by coarse gravels, rapidly shifting medial bars and channels, subsequent in-channel deposition, and sheet-like sand deposition. The Denver Fm lacks the lenses and stringers of gravel which are typical of a braided stream environment. Meandering streams, characterized by medium- to fine-grained sands, clays, and lignites and by lateral accretion of point-bar deposits, exhibit good lateral continuity. The predominant style of fluvial deposition at RMA is meander belt (Morse, 1979).

A variety of sediments were deposited within the meandering stream environment. Sandstones were deposited along the streams. Interbedded silty sands, thin lignites, carbonaceous shales, and mudstones represent adjacent flood basin environments. The flood basin environment includes poorly drained backswamps where lignites accumulated. These lignites are interbedded with clayshales that were deposited by flood waters that breached the channel levees. As the channel meandered across its flood plain, some of the lignites were eroded and redeposited as carbonaceous fragments within the sandy zones. Local deposition of sands in the flood basin could be due to formation of flood basin deposits during flood events. All of these sediments are represented in the Denver Fm.

An understanding of the relationship between sediments and their distribution is essential for correlation and interpretation. Understanding the fluvial depositional environment of the Denver Fm has facilitated the correlation of numerous hydrostratigraphic zones within the formation.



EXPLANATION

	Qpp	Post Piney Creek Alluvium (Quaternary)
	Qp	Piney Creek Alluvium (Quaternary)
	Qes	Eolian Sand (Quaternary)
	Ql	Loess (Quaternary)
	Qb	Broadway Alluvium (Quaternary)
	Qlo	Louviers Alluvium (Quaternary)
	Qv	Verdos Alluvium (Quaternary)
	Tkd	Denver Formation (Upper Cretaceous & Tertiary)

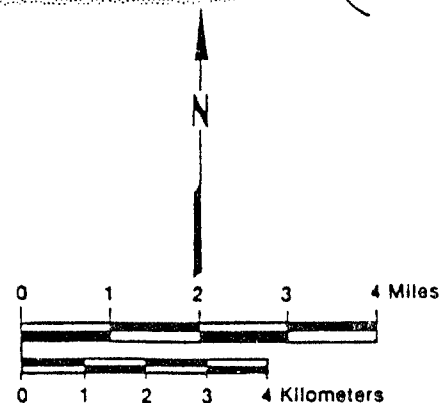


Figure 3.1-1
GEOLOGIC MAP OF ROCKY MOUNTAIN
ARSENAL AREA

SOURCE: LINDVALL (1980, 1983)

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

MAJOR DIVISIONS				TYPICAL NAMES
COARSE-GRAINED SOILS MORE THAN HALF IS COARSER THAN NO. 200 SIEVE	GRAVELS MORE THAN HALF COARSE FRACTION IS LARGER THAN No. 4 SIEVE SIZE	CLEAN GRAVELS WITH LITTLE OR NO FINES	GW	WELL GRADED GRAVELS WITH OR WITHOUT SAND, LITTLE OR NO FINES
			GP	POORLY GRADED GRAVELS WITH OR WITHOUT SAND, LITTLE OR NO FINES
		GRAVELS WITH OVER 12% FINES	GM	SILTY GRAVELS, SILTY GRAVELS WITH SAND
			GC	CLAYEY GRAVELS, CLAYEY GRAVELS WITH SAND
	SANDS MORE THAN HALF COARSE FRACTION IS SMALLER THAN NO. 4 SIEVE SIZE	CLEAN SANDS WITH LITTLE OR NO FINES	SW	WELL GRADED SANDS WITH OR WITHOUT GRAVEL, LITTLE OR NO FINES
			SP	POORLY GRADED SANDS WITH OR WITHOUT GRAVEL, LITTLE OR NO FINES
		SANDS WITH OVER 12% FINES	SM	SILTY SANDS WITH OR WITHOUT GRAVEL
			SC	CLAYEY SANDS WITH OR WITHOUT GRAVEL
FINE-GRAINED SOILS MORE THAN HALF IS FINER THAN NO. 200 SIEVE	SILTS AND CLAYS LIQUID LIMIT 50% OR LESS		ML	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTS WITH SANDS AND GRAVELS
			CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, CLAYS WITH SANDS AND GRAVELS, LEAN CLAYS
			OL	ORGANIC SILTS OR CLAYS OF LOW PLASTICITY
	SILTS AND CLAYS LIQUID LIMIT GREATER THAN 50%		MH	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS, FINE SANDY OR SILTY SOILS, ELASTIC SILTS
			CH	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS
			OH	ORGANIC SILTS OR CLAYS OF MEDIUM TO HIGH PLASTICITY
	HIGHLY ORGANIC SOILS		PI	PEAT AND OTHER HIGHLY ORGANIC SOILS

Figure 3.2-1
UNIFIED SOIL CLASSIFICATION
SYSTEM (ASTM D-2487)

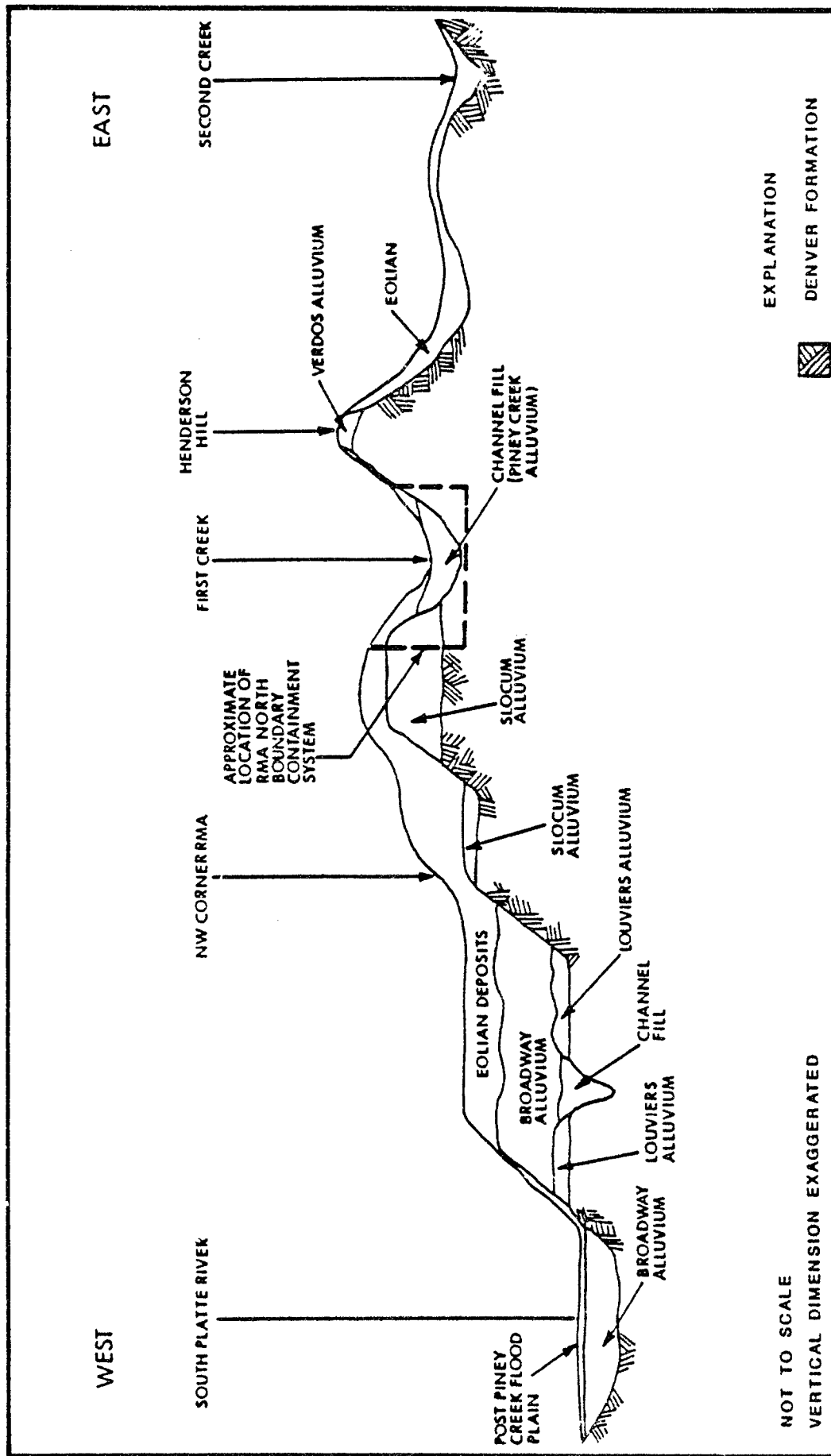
Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

ERA	PERIOD	EPOCH	AGE	FORMATION
CENOZOIC	QUATERNARY	HOLOCENE		Post Piney Creek
				Piney Creek
				Eolian
		PLEISTOCENE	Wisconsin	Loess
				Broadway
				Louviers
			Illinoian	Slocum
			Kansan	Verdos

NOT TO SCALE

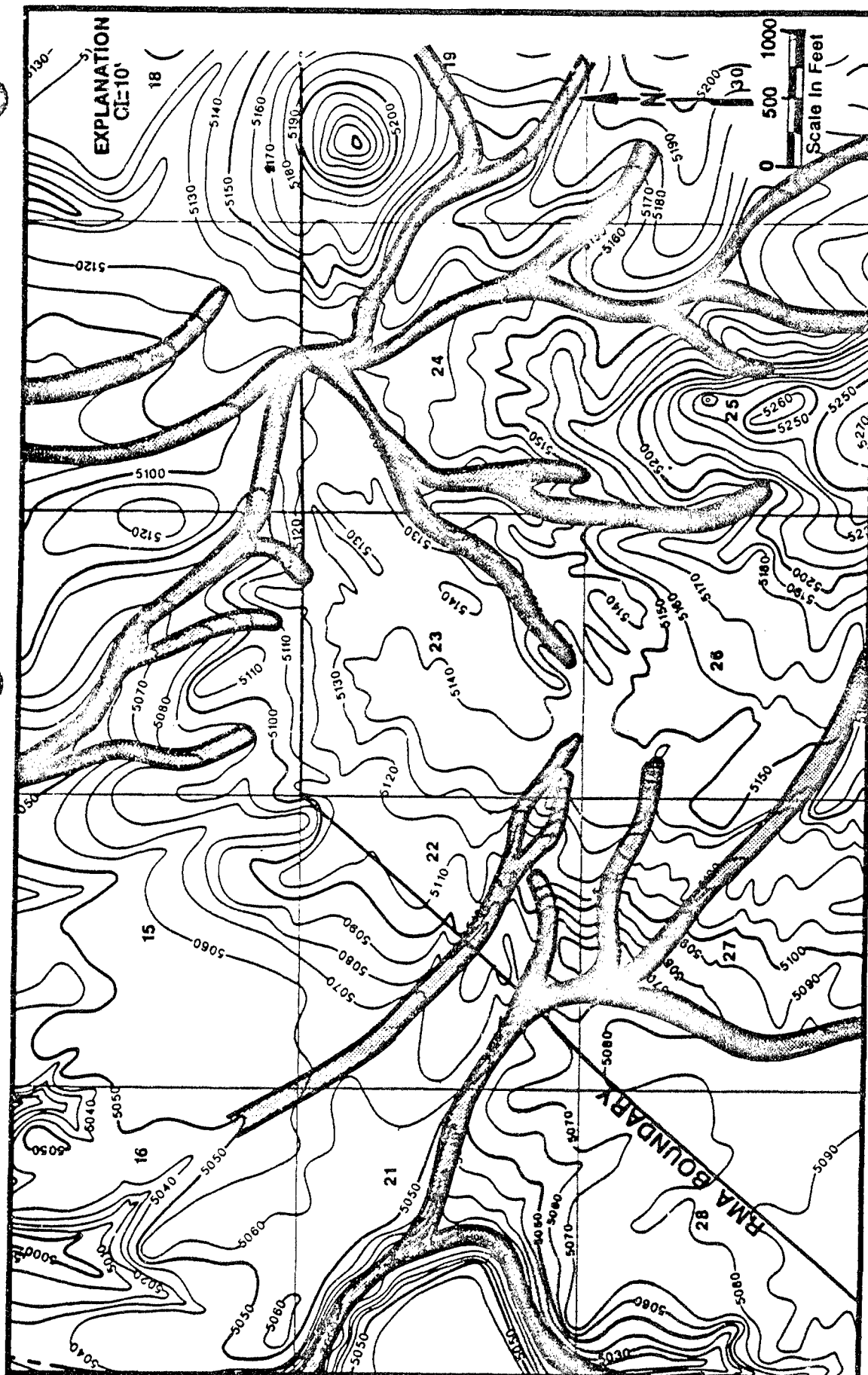
Figure 3.2-2
QUATERNARY COLUMNAR SECTION
 SOURCE: Modified From MKE (1988)

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland



Prepared for:
 U.S. Army Program Manager's Office
 For Rocky Mountain Arsenal
 Aberdeen Proving Ground, Maryland

Figure 3.2-3
 GENERALIZED EAST-WEST CROSS SECTION FROM THE
 SOUTH PLATTE RIVER TO THE NORTHEAST CORNER OF
 RMA



Prepared for:

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Aberdeen Proving Ground, Maryland

Figure 3.3-1
BEDROCK ELEVATION AND INFERRED PALEOCHANNEL LOCATION

SOURCE: ESE 1988

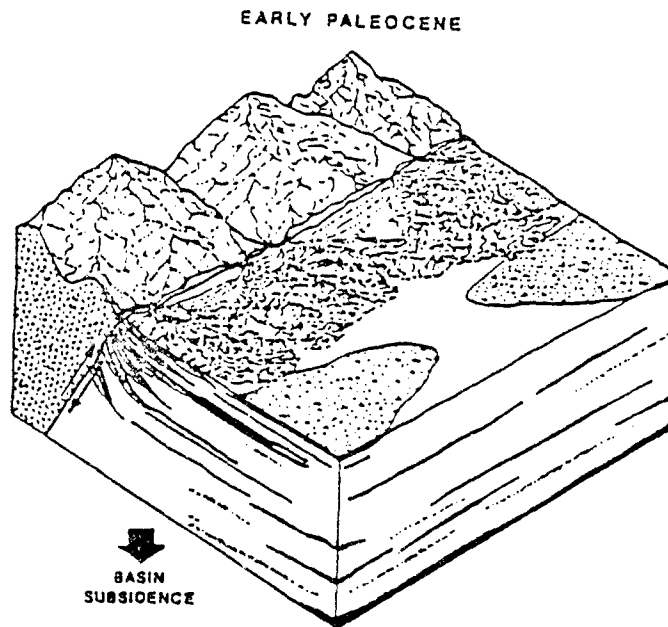


Figure 3.4-1a
From Kirkham and Ladwig (1979)

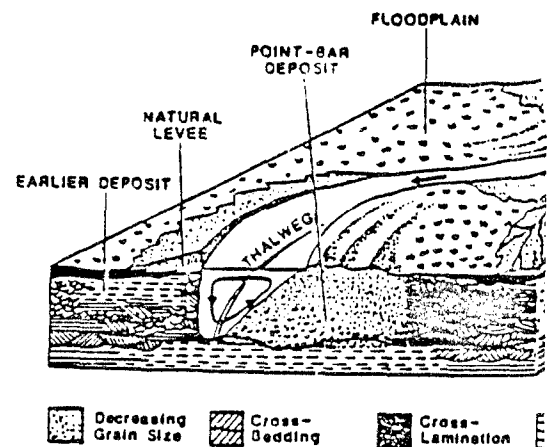


Figure 3.4-1b
Modified from

Figure 3.4-1
SCHEMATIC DIAGRAMS DEPICTING DENVER FM.
DEPOSITIONAL ENVIRONMENTS
SOURCE: ESE, 1988

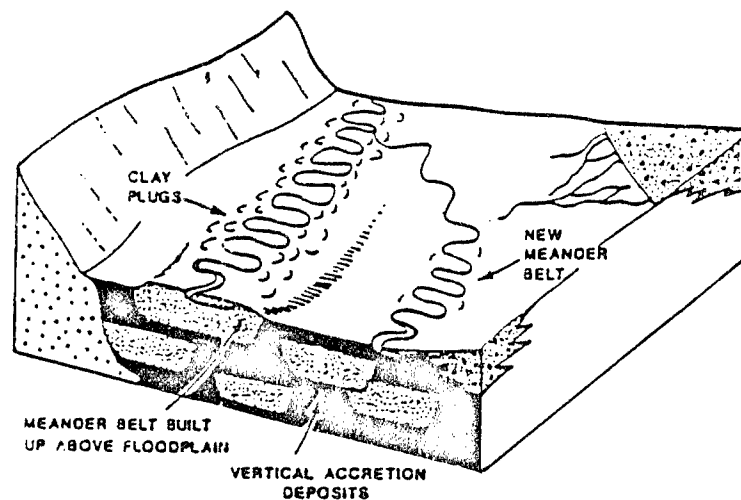
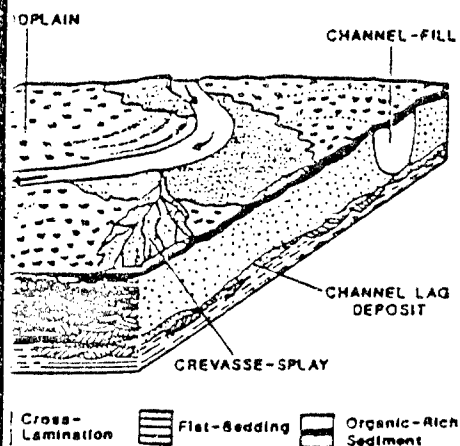


Figure 3.4-1c
From Allen (1965)



3.4-1b
Modified from Allen (1965)

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland

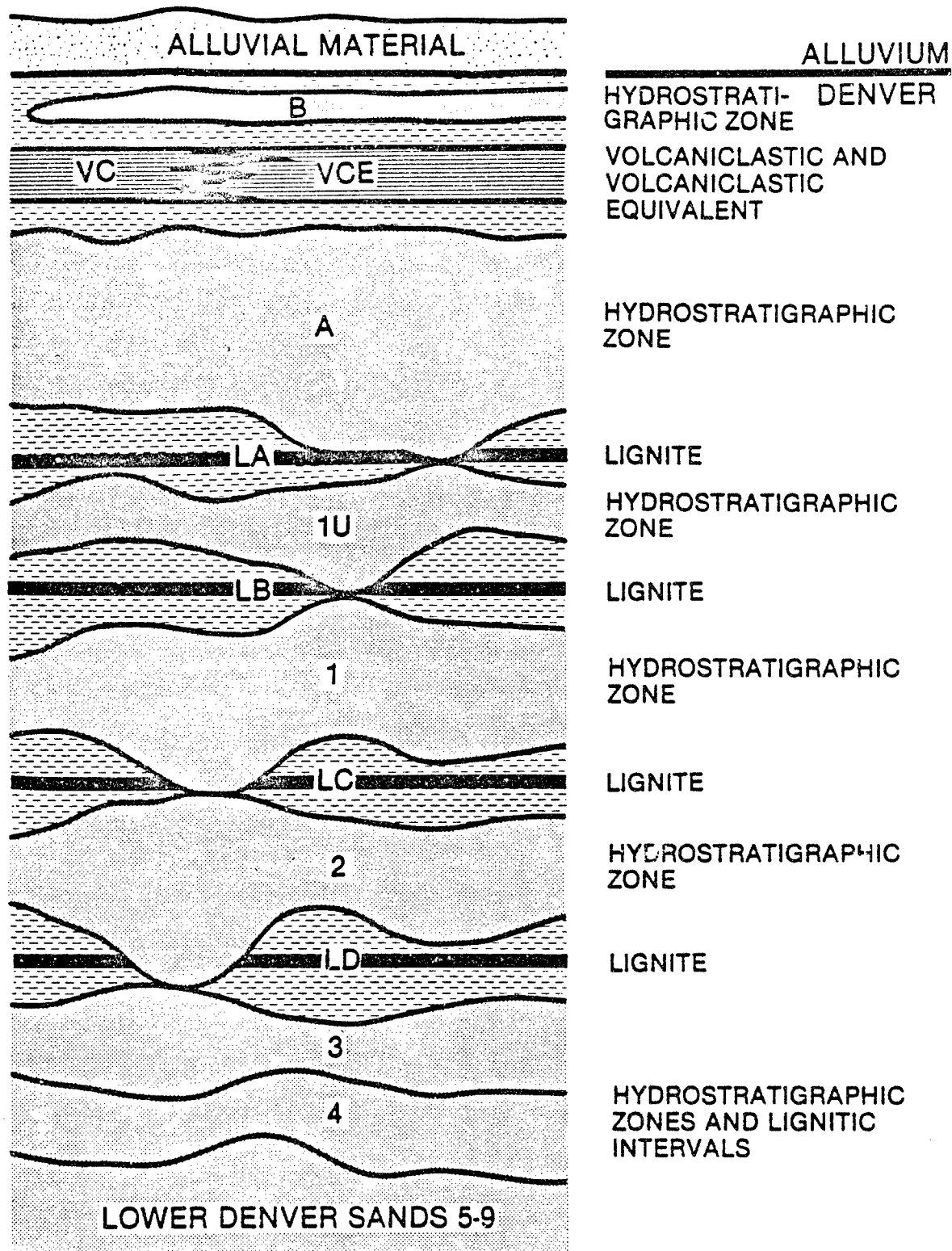


Figure 3.4-2
GENERALIZED DENVER FORMATION
STRATIGRAPHIC COLUMN

SOURCE: ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

4.0 HYDROGEOLOGY

An interpretation and discussion of the hydrogeologic conditions encountered within the Task 25 study area are needed to define the locations of potential contamination pathways and the rates of contaminant transport. RMA lies in the northwest portion of the Denver Ground Water Basin. The two water bearing units of interest are the unconsolidated Quaternary alluvium and the underlying Late Cretaceous to Tertiary Denver Fm. Although these two units are in physical contact, their hydrologic properties are distinctly different and they generally behave as independent aquifers, although in some areas they are interconnected. The hydrogeologic conditions exhibited by these two units are locally complex. The complexity stems not only from the diversity of geologic environments encountered, but from the activities of the containment systems. Of the two systems, the majority of site specific data are available in the vicinity of the NBCS.

The character and spatial distribution of the aquifers within the Denver Basin have been previously investigated and reviewed by several different authors. The hydrogeologic information which provides the background for this study is largely based upon previous investigations performed by Vispi (1978, RIC#81266R70), Robson and Romero (1981, RIC#82350M02), May (1982, RIC#82295R01), Thompson *et al.* (1985, RIC#86078R01), and PMSO (1987a, RIC#87320R01 and 1987b, RIC#88054R01).

A discussion of the alluvial aquifer will precede that of the Denver Fm to correspond to the natural sequence encountered. The recharge to the respective aquifers, the water level configurations, hydraulic conductivities, flow directions and quantities, and the discharge from the aquifers will be discussed. Where appropriate, the findings from other tasks, completed or ongoing, that incorporate portions of the Task 25 study area will be included. In particular the results of Tasks 36 and 39 and the Water Remedial Investigation Report (Ebasco, 1989, RIC#89186R01) will be referenced.

4.1 ALLUVIAL HYDROGEOLOGY

The alluvial hydrogeology is made complex by the heterogeneous nature of unconsolidated materials comprising the alluvial aquifer, and by the direct effects of man's activity on this aquifer. Section 3.0 describes the characteristics of the eolian and fluvial materials throughout the study area. Figures 3.2-2 and 3.2-3 illustrate the stratigraphic and depositional relationship of these materials. The alluvial aquifer has been the initial recipient of contamination discharged to the subsurface at RMA. In the Task 25 area, this factor is especially important due to the presence of Basins C, D, E, and F. Materials comprising the alluvium have not only served as the recipient of contaminants, but in some instances as the filtering and transport medium of contaminants to the underlying Denver Fm.

The surficial deposits as described in Section 3.0 are composed of clays, silts, sands, and gravels. The alluvial aquifer, which consists of the saturated material, is predominantly coarser sands and sandy gravels. These coarser deposits are generally the surficial material in contact with bedrock. The underlying Denver Fm is composed predominantly of relatively impervious shales and claystones with lesser amounts of siltstones and sandstones.

The alluvial aquifer in the Task 25 study area is generally classified as unconfined, heterogeneous, and transversely isotropic. In some areas, the potentiometric surface extends slightly above the sands and gravels into the upper fine-grained clay and silty sand layers of the aquifer, which can produce artesian conditions. In this type of aquifer, the hydraulic conductivity (K) of the upper fine-grained deposits is notably lower than the K of the lower sands and gravel. However, the K of the upper deposits is not so low that the horizontal flow component can be ignored. An aquifer under these conditions can be described as a combination of the traditional semi-confined and unconfined aquifers or as semi-unconfined (Kruseman and DeRidder, 1983).

Locally, the bedrock composition directly underlying the alluvium may consist of poorly cemented subcropping sandstone and siltstone lenses (May, 1982, RIC#82295R01). In these areas the alluvium and the upper Denver Fm are considered hydraulically connected and can act as one hydrogeologic unit. Local hydrologic conditions just upgradient of these areas may show an upward vertical flow potential from the Denver Fm to the alluvium.

The hydrogeology of the alluvium will be discussed in terms of recharge, ground-water movement, and discharge. This discussion does not imply that contaminants will in all cases follow the same pathways. Section 5.0 will more specifically address contaminant distribution.

4.1.1 AQUIFER RECHARGE

The alluvial aquifer in the Task 25 study area receives recharge from direct infiltration of precipitation, and has historically received recharge from Basins C, D, and E. Additionally, recharge to the study area occurs at the NBCS and NWBCS, through First Creek, through irrigation ditches and canals, and through the general ground-water flow from areas to the south of the Task 25 study area.

Because of the high evapotranspiration rates in the RMA area, the amount of recharge reaching the aquifer by direct infiltration of precipitation is small. The average annual precipitation based on 39 years of data at the Stapleton International Airport (SLA) station is 15.25 inches, compared to an estimated average annual evapotranspiration rate of 20.4 inches.

The amount of recharge that historically was able to reach the alluvial aquifer via the several basins located in Section 26 is unknown. Neither level changes within the basins nor the volume of effluent received by the basins were monitored. On the basis of design construction, however, the basins may historically have been a significant source of recharge.

First Creek is an intermittent stream that transects the NBCS area and is thought to have a significant influence on the alluvial aquifer. Over the past two years, stream gaging has been conducted at the southeast corner of RMA and at the north boundary where First Creek exits RMA. Evaluation of data collected at these stations between October 1985 and June 1987 shows that, on the average, First Creek is losing water onpost. This assessment is somewhat complicated by the fact that during specific months of high precipitation, First Creek gains water along various onpost reaches. Gaining periods generally correspond to high precipitation periods during which surface runoff as well as elevated water tables contribute water to First Creek between the two gages. Nevertheless, First Creek experiences an overall net loss of water to the alluvial aquifer at RMA.

Since no gaging has been conducted immediately upgradient from the study area, it is difficult to assess whether the northernmost reach of the stream is gaining or losing water. It is probable that different reaches of First Creek are losing water to and gaining water from the alluvial aquifer simultaneously. Whether First Creek is losing or gaining water depends upon the quantity of base flow and seasonal water-table fluctuations in a specific area.

Gaging of First Creek at Highway 2 began in July 1986. Evaluation of these data in conjunction with data obtained at the north boundary gaging station delineates some definitive trends offpost. First, during high flow periods, the upstream gage station recorded significantly higher flows than at the Highway 2 station. The majority of this water appears to be lost to the alluvial aquifer via infiltration from First Creek and the surface impoundment located in the eastern portion of Section 14. From July 1986 to June 1987, losses between these two points exceeded approximately 100 gpm. Much of the noted losses were observed during storm events during which the Highway 2 gage was inundated. During these storms, the Highway 2 gage probably underestimated flows and, thus, First Creek losses could be overstated. However, considering that evaporation would only represent a small fraction of water loss during base flow periods, it is evident that First Creek is losing water to the alluvial

aquifer along this reach. The relative contribution, specifically from the surface impoundment, as opposed to First Creek itself, is thought to be significant because the impoundment can retain water during storm events and act as a "spreading basin" during no flow periods in First Creek. Since the impoundment covers approximately 8 acres, substantial recharge to the alluvial aquifer could be occurring throughout the year. This is substantiated by water level declines in the impoundment that exceed 1.5 ft/month.

During no flow periods at the north boundary gage, small flows have been measured at the Highway 2 station. These data indicate that during low flow periods First Creek may gain water from the alluvial aquifer. Surface runoff during these low flow periods, primarily during the summer and fall, is generally nonexistent and is not believed to be responsible for the downstream flows. This assessment is substantiated by the presence of ground-water contaminants at the offpost Highway 2 surface water sampling station that have not been detected in First Creek onpost.

The Burlington Ditch and the O'Brian Canal to the northwest were found to flow throughout much of the year. The average daily flow at the Burlington Ditch headgate for 1986 was 323 acre-feet (ac-ft) and for 1987 was 428 ac-ft. Losses from the ditch and from the canal are estimated by the ditch company to be 30 percent and 25 percent, respectively. Recharge from the ditch and canal will tend to create a temporary ground-water ridge during continuous flow periods.

Another potential source of recharge, historically, was the sanitary sewer system that terminated in Section 24. The amount of recharge associated with the sewer line and treatment plant was probably minor.

Insufficient data exists to develop a quantitative estimate of the recharge occurring from all the potential sources; however, an approximation of recharge from direct infiltration of precipitation is 373 acre-feet per year (ac-ft/yr). This is based on an

average annual precipitation of 15.3 inches, of which 5 percent recharges the approximately ten square miles of the Task 25 area.

4.1.2 WATER TABLE CONFIGURATION

A water table map for the Task 25 study area, contoured on a 5-ft interval, was prepared for each of the four quarters of FY87. These maps are based on water levels for all alluvial wells in the study area, including category 1, 2, and 3 wells. A description of the categories of alluvial wells is included in Section 2.0. In areas of limited data some category 4 wells were included, if the water levels fit the local trends. In some areas, where the alluvium is designated as unsaturated, water levels in the underlying Denver Fm were found to be comparable to those in the surrounding alluvium. These Denver Fm water levels were considered in the construction of the water table contour maps and are indicated as dashed lines. The water table maps are presented in Figures B-25A through B-25D. In addition, detailed water table maps were prepared for the NBCS and the NWBCS for each quarter of FY87. These maps are presented in Figures B-26A through B-27D. The resulting general configuration for each of the quarters are quite similar, and indicate that flows are toward the north and northwest RMA boundaries.

4.1.2.1 General Trends

Water table gradients, as determined from the water table contour maps, provide an indication of the permeability of the alluvial sediments and an indication of the effects of the barrier systems. In Sections 23 and 24, the gradients range from 0.001 ft/ft to 0.03 ft/ft. These relatively flat gradients reflect the effects of the containment systems. The lowest gradients in the study area are commonly present along the central axes of deeply buried alluvial paleochannels containing coarse sediments. These occur in Sections 23 and 24 upgradient of the NBCS. The hydraulic gradients vary in the immediate vicinity of the NBCS and the NWBCS. Gradients in Sections 22 and 27, upgradient of the NWBCS, do not indicate a great deal of variation. The gradients in Sections 22 and 27 immediately upgradient of the NWBCS vary between 0.02 and 0.03 ft/ft. The effects of the containment system are less pronounced

compared to the NBCS because of the bedrock highs in the area. In the western half of Section 27 the gradient is as low as 0.003 ft/ft. Water levels in this area appear to be effected by the pumping at the NWBCS, as the contour lines are deflected to the north.

The steepest gradients in the study area occur where ground water is moving through less permeable alluvial material, or through the Denver Fm underlying unsaturated alluvial areas. In areas adjacent to high bedrock elevations, where sediments are likely to be more heterogeneous, gradients are steeper. Gradients in these areas are as high as 0.03 ft/ft.

4.1.2.2 Hydrographic Profiles

The variations in water table elevation between quarters indicate the small amount of recharge that actually occurs. Average differences of less than 2.5 ft are noted between the driest and wettest quarters, although more extreme fluctuations are observed adjacent to First Creek. To illustrate the water level trends both upgradient and transverse to the NBCS and the NWBCS, four hydrographic profiles were constructed. Figure 4.1-1 presents a location map for these profiles.

An east to west hydrographic profile was constructed along a line approximately 1,100 ft upgradient of the NBCS (Figure 4.1-2). This profile illustrates the variations in water levels across the north trending paleochannels. Water level fluctuations illustrated on this profile vary between approximately 1 ft at Well 23160 to approximately 5 ft at Well 24113. The water level fluctuations observed in Well 24106 illustrate the influence of First Creek. Generally, the highest water levels are noted in the spring of each year and reach a low during late summer or fall. Near First Creek, the water table elevations in the winter months may exceed that of the spring months due to surface infiltration.

Higher water table configurations in the winter and spring months are indicative of increased snow melt and rainfall. Although the trends may differ somewhat from year

to year, varying seasonal recharge from direct infiltration of precipitation and other surface water bodies are primarily responsible for the minor seasonal water table fluctuations.

A hydrographic profile constructed along a southwest to northeast line through Sections 23 and 24 illustrate the change in water level across the NBCS (Figure 4.1-3). The wells on this profile indicate minimal seasonal variation and illustrate the decrease in water levels across the boundary. The downgradient water levels are affected by the presence of the soil-bentonite barrier and limited recharge from downgradient recharge wells. Many of the downgradient wells have exhibited declining water levels over the last decade. There are areas near the North Bog where substantial amounts of the NBCS effluent water were being recharged and these areas exhibit a higher water table than a decade ago.

A hydrographic profile constructed along a southwest to northeast line approximately 850 ft upgradient of the NWBCS illustrates minimal seasonal variation (Figure 4.1-4). The profile illustrates a decrease in water levels in the vicinity of the NWBCS pumping wells relative to water levels in wells southwest of the boundary system. The water levels are much higher in Well 22049 near the northeastern portion of the boundary system. This well is located in an area of higher bedrock elevation and the water level in this area reflects the bedrock-slope configuration.

The water table elevations across the NWBCS are relatively constant as illustrated by a southeast to northwest hydrographic profile (Figure 4.1-5). This profile illustrates minimal seasonal variation and a general decrease in water levels across Section 27, following the general bedrock configuration.

4.1.2.3 Well Hydrographs

A series of hydrographs were constructed for alluvial wells which include all water level data for the years 1981 through 1987. These hydrographs illustrate the long term water level trends for a number of wells in the Task 25 study area. Hydrographs

are presented in Figures B-35 through B-67. The hydrographs illustrate general increases or decreases in water level over time as well as the presence of yearly seasonal fluctuation in water levels. The wells in the Task 25 area can be grouped in terms of general water level trends.

The hydrographs for wells located upgradient of the NBCS (23178, 23118, 23119, and 23120) indicate stable water levels with seasonal fluctuations of up to 2 ft. Hydrographs for wells located upgradient of the NBCS, in the vicinity of First Creek, indicate stable but fluctuating water levels. Examples of this trend are the hydrographs from Wells 24115, 24106, 24158, and 24003.

The hydrographs for wells downgradient of the NBCS illustrate a general increase in water levels between 1982 and 1984 and a decrease in water level elevations from 1984 to the most recent measurements in 1987. The hydrograph for Well 23047 illustrates this configuration. This hydrograph curve type is not illustrated by wells in the vicinity of First Creek downgradient of the NBCS. Wells downgradient of the boundary - 24163, 24164, and 24166 - indicate a general increase into 1984 and then a stabilization of water levels through the most recent measurements in 1987. The water levels in these wells are probably affected by recharge from First Creek and from the treated water recharged in the North Bog area. These hydrographs indicate varying seasonal water level fluctuations from year to year.

Hydrographs constructed for wells upgradient of the NWBCS indicate stable or slightly declining water levels since 1981. Examples of this trend include water levels from Wells 22029 and 27062. Water levels from many of these wells illustrate low magnitude seasonal water level fluctuations. Hydrographs constructed for wells downgradient of the NWBCS indicate stable water levels with fluctuations of up to 3 ft. Well hydrographs that illustrate these trends include 22017 and 22022.

4.1.3 SATURATED THICKNESS

Saturated thickness varies with the bedrock topography. Figure B-28 presents a contour map of saturated thickness for the Task 25 area. Water level data from the third quarter FY87 were used to construct the saturated thickness map. Where bedrock highs exist the alluvium is quite thin or absent, and where paleochannels occur, saturated thicknesses can be as much as 30 ft. In the eastern portion of Sections 25 and 24, a thick saturated zone corresponds to the First Creek drainage paleochannel. This zone is up to 30 ft thick in Section 25. As it trends north toward the NBCS, the maximum thickness decreases to 25 ft (Figure B-28). In the offpost area, north of the boundary system, the maximum saturated thicknesses are approximately 25 ft along the First Creek paleochannel.

The saturated thickness of the unconsolidated alluvial materials in the NBCS area ranges from 0 to 20 ft as shown in Figure B-28. Toward the NWBCS, saturated thicknesses of up to 30 ft have been mapped. There is a north to south trending paleochannel in Section 27 with saturated thicknesses of up to 30 ft. Saturated thicknesses near the southwest portion of the boundary are over 20 ft, compared to less than 10 ft at the northeast end.

Trends of contours depicting saturated thickness reflect potential flow pathways and the areas of higher transmissivity (T). Comparison of maps showing saturated thickness and T illustrate this relationship (Figures B-28 and B-29).

4.1.4 AQUIFER PARAMETERS

A considerable amount of review and analytical work was conducted in association with Task 36 to estimate the alluvial aquifer parameters of hydraulic conductivity (K) and apparent specific yield (SYA). Because data analysis and interpretation from that effort are applicable to the Task 25 area, the pertinent portions are incorporated in this report. Similar analytical work was not possible in the NWBCS area because of sparse data.

In previous studies, the hydrogeologic properties of K and storativity of the alluvial aquifer in the NECS area were determined by slug and pumping tests (Zebell et al., 1979, RIC#81266R19; Mitchell, 1976, RIC#81281R04; Vispi, 1978, RIC#81266R70; Black and Veatch, 1980, RIC#81266R25). The location of these tests are shown on Figure 4.1-6. A determination of the aquifer K is essential for determining flow rates and times of travel. Values of storativity are necessary for predicting water table fluctuations due to natural and man-made stresses.

ESE reanalyzed data of seven pumping tests, five completed by WES (Vispi, 1978, RIC#81266R70) and two additional tests conducted by Black and Veatch (1980, RIC#81266R25). Reinterpretation of these data indicate that the alluvial aquifer responds as an unconfined aquifer in most cases, but in some areas acts as an unconfined aquifer with a delayed yield.

Values of T and K were also determined in the study area by slug tests (Zebell et al., 1979, RIC#81266R19). Slug-test-derived K values for the alluvial aquifer are more variable than those derived from pumping tests. The values obtained from this method apply only to the immediate area adjacent to the test well, and may not represent conditions more than just a few feet away.

Reanalysis and evaluation of aquifer testing data was performed to confirm calculated values, because reported aquifer K and storativities varied significantly. Battelle-Moody (Thomas et al., 1977, RIC#81340R03) reanalyzed three pumping tests performed by WES (Mitchell, 1976, RIC#81281R04) and their results differed from the WES values. The reexamination of these data was undertaken by Battelle-Moody using a transient analysis. Based upon the results of the transient analysis for three wells for which acceptable data exists, it was determined that their storage coefficient was 0.05, while T ranged between 6,210 to 19,100 gallons per day per foot (gpd/ft). T, K, and SYA values are given in Table 4.1-1.

Table 4.1-1. Transmissivity (T), Hydraulic Conductivity (K), and Apparent Specific Yield (SYA) from Pumping Tests

Site Well No.	(Bore No.)	Aquifer Test By	T (gpd/ft)	K*** gpd/ft ²		SYA
				K _h	K _v	
24029	(345)	WES (Vispi, 1978)*	30,000	3,000	2.0-100	0.18
24043	(549)	WES (Vispi, 1978)*	15,500	1,550	--	0.01
23049	(368)	WES (Vispi, 1978)*	45,000	7,250	--	0.25
23096	(529)	WES (Vispi, 1978)*	79,000	7,500	--	0.21
23067	(548)	WES (Vispi, 1978)*	20,000	2,000	--	0.03
24153	(1036)	Black & Veatch (1981)	18,500	1,760	0.80	0.02
24150	(1032)	Black & Veatch (1981)	19,400	1,760	12-84	0.01
24025	(221)	WES (Mitchell, 1976)**	8,020	1,670	--	0.048
23024	(203)	WES (Mitchell, 1976)**	6,210	887	--	0.050
24013	(209)	WES (Mitchell, 1976)**	19,100	1,270	--	0.054

* Transmissivity and apparent specific yield from ESE reanalysis.

** Transmissivity and apparent specific yield from reanalysis by Battelle-Moody (Thomas et al., 1977, RIC#81340R03).

*** K_h and K_v denote horizontal and vertical hydraulic conductivity, respectively.

Source: ESE, 1988

There is general agreement between the mean K values obtained from pumping- and slug-type aquifer tests, although several of the values obtained from slug tests seem to underestimate K due to incorrect assumptions and interpretation of the data. Values of K obtained from these slug tests ranges from 225 to 5,260 gallons per day per square foot (gpd/ft²) with a mean of 1,621.5 gpd/ft² (Zebell *et al.*, 1979, RIC#81266R19).

Aquifer parameters for alluvial materials in the vicinity of the NWBCS are based in part on previous work and in part on the comparative analyses conducted for Task 36. Previous work includes tests conducted by May (1982, RIC#82295R01) on Well NW-11. Results from that test indicated an average T of 405,000 gpd/ft and an average K of 17,690 gpd/ft². This particular well test indicated conditions more representative of a confined aquifer. A test on Well W-4 (USACE, 1983, RIC#85176R01 and 1986) indicated that the aquifer was responding under unconfined conditions. Values of T were 210,000 gpd/ft and values of K were 8,557 gpd/ft². Because of the variability inherent in most aquifer tests, values obtained should be viewed as order of magnitude estimates. Detailed, more site-specific values would require more sophisticated techniques.

4.1.5 CHARACTERIZATION OF THE SATURATED INTERVAL

Alluvial lithology within the saturated interval was characterized by the appropriate USCS classification as presented in Figure 3.2-1. Associated K values were assigned to the alluvium at each well location. The reanalysis of aquifer tests conducted in Sections 23 and 24 on RMA have been used to provide estimates of K for different soil groups within the alluvial aquifer. These average values are presented in Table 4.1-2. These values were obtained by correlating the K determined from aquifer tests to the lithologies in pumping and observation wells. Estimates were also made for the fine grained soils not included in pumping tests.

Table 4.1-2. Hydraulic Conductivity of Combined Soil Groups in the Alluvial Aquifer

Classification	Description	Hydraulic Conductivity (gpd/ft ²)
(SP-GW)	Well-graded gravels or gravel-sand mixtures with little or no fines combined with poorly graded sands.	7,000 - 7,500 (928 to 1008 ft/day)
(SP-GP)	Poorly graded gravels, or gravel sand mixtures with little or no fines combined with poorly graded sands.	3,000 (389 ft/day)
(SP-SW)	Poorly to well-graded sands or gravelly sands with little or no fines	1,850 (245 ft/day)
(SP)	Poorly graded sands or gravelly sands, little or no fines	1,700 (230 ft/day)
(SM-SP)	Silty sands, sand-silt mixtures combined with poorly graded sands or gravelly sands	1,500 (202 ft/day)
(SM)*	Silty sand, sand-silt mixture	25 to .02
(ML)*	Inorganic silts	25 to .02
(GC and SC)*	Clayey sands, sand clay mixture	~0.02 to 0.0
(CL)*	Inorganic clay	~0.02 to 0.0

* From the California Department of Transportation.

Source: ESE, 1988.

Alluvial K values derived by this assessment range from 0.02 to 7,000 gpd/ft². The values presented are not intended to represent absolute K values but instead are intended to indicate areas of relatively high K. This assessment was conducted to define permeable pathways in the alluvium and to determine the association of specific K ranges with alluvial geologic units described in the Task 25 area.

Table A-3 presents the estimated T for each alluvial well in the Task 25 study area. If the saturated interval contained more than one lithology, a weighted average K was calculated. Integration of the information from this K assessment and alluvial geologic assessments (MKE, 1988) indicate that the relatively higher K values are associated with coarser grained alluvial material. This alluvial material includes the Verdos, Slocum, Louviers, and Broadway units. These units are described in Section 3.2.2.

K of 3,000 gpd/ft² were indicated for over half of the Slocum wells evaluated. This unit occurs primarily in the eastern portion of Section 23, western portion of Section 24, and northwestern portion of Section 26. Lithologic variations within this unit are apparent, however, as K may drop to less than 1 gpd/ft² in some of the Slocum material (Wells 23210 and 23002).

Broadway, Louviers, and channel-fill alluvial units identified by MKE (1988) are characterized by K values between 1,000 and 3,000 gpd/ft² in west central portions of Section 27 and the southwestern quarter of Section 22.

Higher K values in the vicinity of the NWBCS cannot be assigned specifically to either the Louviers or Broadway, as both of these units exhibit K values of 3,000 gpd/ft² in this area. Channel-fill material in the southwestern portion of

Section 26 and in the southeastern quarter of Section 27 appear to be associated with lower relative K material and unsaturated alluvium (Wells 26088 and 27050). The sparse data in this area limits evaluation.

The Verdos occurs in the Task 25 study area as isolated caps on bedrock highs which are generally unsaturated. However, the coarse nature of the Verdos sediments indicate that this unit probably exhibits relatively high K values.

Water levels from the 3rd quarter FY87 (spring) were used to calculate saturated thickness values. Because saturated thickness exhibits minimal seasonal variation, transmissivity values were calculated using water level data from one quarter. The 3rd quarter FY87 was selected for calculations because it represents the most extensive water quality sampling event of FY87 and the results were used to assess contaminant distribution. The K values and saturated thickness at each well were used to calculate T. A contoured representation of the alluvial T values is presented in Figure B-29. The T map indicates areas of relatively high and low K, as well as areas of relatively thick saturated alluvium, which may delineate preferred contaminant pathways in the alluvium.

Transmissivity values in Section 23 occur in excess of 30,000 gpd/ft in eastern and southeastern portions of the section (Wells 23052, 23134, 23095, and 23072). Relatively higher T values occur in southwest to northeast trending belts in the eastern portion of the section. The relatively low K zone in east-central Section 23 is also reflected in a relatively lower T zone of 10,000 gpd/ft. Included in this zone are Wells 23011, 23010, 23084, 23009, and 23051. A narrow north to south trending zone of relatively high T occurs at the southern section line. This zone includes Well 23035 and is flanked by dry alluvium on the west and relatively low T material on the east.

In Section 24, relatively higher T zones correspond with relatively higher K zones in north central portions of the section. This area includes Wells 24006, 24113, 24114,

24055, 24099, and 24098. However, due to greater saturated thickness, relatively lower K areas along the west central portions of the section (Wells 24001 and 24092) correspond to higher T values. Relatively lower T values occur along the eastern margin of Section 24.

The saturated alluvium in Section 27 exhibits varying T values. East central portions of the section exhibit T values of less than 10,000 gpd/ft. This area includes Wells 27082, 27040, 27041, and 27079. Relatively high K values are not reflected in the T values due to lesser saturated thickness. The T values in western and northwestern portions of the section occur in excess of 40,000 gpd/ft, and reflect the relatively higher K in this area.

Much of the alluvial material in Section 22 is unsaturated. T values in the saturated areas of this section occur in excess of 30,000 gpd/ft, but are relatively lower than in areas of equivalent K to the south in Section 27 because of less saturated thickness.

4.1.6 FLOW DIRECTIONS AND RATES

The two major flow directions in the Task 25 area have been fairly well established as being toward the NBCS and the NWBCS. These pathways are largely controlled by the paleochannels and the sources of recharge to those channels. Flow toward the NBCS is divided by a bedrock high in the southeast and southwest of Sections 23 and 24, respectively (Figure 4.1-7). The flow to the northeast and north follows the paleochannel of First Creek. According to earlier estimates of Thompson *et al.* (1985, RIC#86078R01), the total ground-water flow reaching the NBCS area ranged between 250 to 325 gpm. This estimate was based upon flow measurements and water level data in the vicinity of the NBCS. Recent estimates of these rates (PMSO, 1987a, RIC#87320R01) range from 200 to 250 gpm with a steady state flow rate estimate of 220 gpm (ESE, 1988b).

Historically, flow toward the NWBCS has been influenced by recharge from Basins A, B, C, D, and E. An estimate of current flow reaching the boundary system is 183 gpm.

Ground-water velocities across the study area vary with local changes in K and gradient, however, these variations are minor. Estimates of ground-water pore velocities range from 1.5 ft/day to 22 ft/day.

4.1.7 DISCHARGE

The two major discharge locations for the Task 25 area are controlled by the activities of each of the containment systems. The pumping of the alluvial aquifer on the upgradient side of these barriers is removing a majority of the flow leaving RMA. A small percentage is discharged to the underlying Denver sands, to First Creek during high flow, and to some extent around the NWBCS.

A review of the data from several cluster well sites in the NBCS area indicates that recharge to the Denver is occurring. In some areas, recharge to the alluvial aquifer from the underlying Denver Fm is occurring where sandstone units subcrop beneath the alluvium (May, 1982, RIC#82295R01). The direction of vertical ground water movement varies throughout the area depending upon the Denver Fm sand unit or clay/shale unit that may be in contact with the alluvium and the relationship between the water table and potentiometric levels.

4.2 DENVER FM HYDROGEOLOGY

Regionally, the Denver Fm consists of a system of interbedded permeable and relatively impermeable sediments. Because of this, a high degree of variability in T and storativity values occur from one area to another. Ground-water flows laterally up dip through sandstone lenses under confined conditions and discharges locally into the alluvial aquifer. The driving head for this up-dip flow results from recharge into outcropping Denver Fm sandstones in other parts of the Denver Basin. Structural mapping by Robson and Romero (1981, RIC#82350M02) indicates that the altitudes

of the base of the Denver Fm range from more than 6,400 ft msl in the southern part of the Basin to less than 4,600 ft msl in the lowest part of the structure. The base of the Denver Fm is at about 5,000 ft msl in the vicinity of RMA.

In the Task 25 study area, the Denver Fm consists of an approximately 250- to 300-ft thick series of carbonaceous clayshales, claystones, and siltstones (May *et al.*, 1980, RIC#81266R48). These fine-grained sediments are interbedded with weakly lithified, more permeable, sandstone units. The sandstone units may be locally unconsolidated, but cementing with calcium carbonate, silica, or other minerals can decrease the K of these sandstone units by two orders of magnitude or more (Ertec, 1981, RIC#81352R135). Where they are uncemented or partially cemented, these sandstone units act as the dominant pathway for transmitting lateral ground-water flow through the Denver Fm.

Where water-bearing sandstone units are confined and heterogeneous, the upper units generally have a potentiometric surface a foot or two below the alluvial water table surface. In areas where Denver Fm sandstones subcrop into the alluvium the water levels of the subcropping units are similar to that of the alluvial water table, indicating an area of potential discharge.

Potentiometric differences between sandstone units in the study area generally indicate downward ground-water movement. Vertical hydraulic gradients observed between distinct units range from 0.002 to 0.4 ft/ft. Generally, sandstone units that are in contact exhibit coincident water levels and can be considered as one hydrostratigraphic zone. Alluvium/Denver Fm interactions and intra-Denver Fm sandstone aquifer interactions are discussed in Sections 4.2.6.1 and 4.2.6.2, respectively.

Over much of the Task 25 study area, the water bearing sandstone units represent fluvial meander belt and flood basin type deposits that grade laterally and vertically into finer-grained materials. Due to lateral and vertical changes in depositional

environment, the sandstone units differ in their capacity to store, transmit, and yield water. In general, the Denver Fm sandstones have a K three orders of magnitude less than the coarsest alluvial sediments. In addition, slug tests and laboratory K tests have shown in some instances that the K of fractured and weathered clay shale is of similar magnitude to that of the Denver Fm sandstones (May *et al.*, 1980, RIC#81266R48).

The Denver Fm hydrogeology is discussed in terms of recharge, ground-water movement, and discharge. Several hydrostratigraphic zones, separated by less permeable lignitic shale zones, have been identified at RMA (Figure 3.4-2). Of these zones, 2, 3, and 4 subcrop most extensively in the northern portion of RMA and are, therefore, of the most interest to the Task 25 study.

The lateral ground-water flow direction within the Denver Fm is generally to the north-northwest. Potentiometric surface maps prepared for each of the characterized hydrostratigraphic zones show this pattern. These potentiometric surface maps are discussed in Section 4.2.2 of this report.

4.2.1 AQUIFER RECHARGE

Regional recharge to the Denver Fm occurs far to the south of RMA where the Denver outcrops and is subject to direct infiltration of precipitation. The elevation of these recharge areas is sufficiently high topographically to cause ground-water movement up dip at RMA. Other recharge to the Denver Fm occurs as a result of the overlying saturated unconsolidated materials having a higher water level elevation than the Denver Fm. This mode of recharge is a key factor in the interpretation of contaminant movement beneath RMA.

Comparatively minor, but significant in terms of contaminant migration, is recharge that results from the activities of man. These activities include well construction, and any excavation work that intercepts Denver Fm units, such as utility trenches. In the areas adjacent to the NBCS, recharge to the Denver Fm has resulted from the

pumping of dewatering wells completed in the formation. These wells, in operation only during 1984, induced flow downward from the overlying alluvium. The amount of recharge reaching the Denver Fm is difficult to quantify because of the variability in lithology and areal extent of each sand zone.

4.2.2 POTENTIOMETRIC HEAD

In the Task 25 study area the Denver Fm has been subdivided into five hydrostratigraphic zones - 1u, 1, 2, 3, and 4. These zones are semi-regional in nature and the subdivision is based on the geologic interpretation presented in Section 3.4, as well as an assessment of potentiometric head and contaminant distribution. Due to the generalized nature of these zones, they include varying amounts of permeable sands and less permeable siltstones and shales. The more permeable sandstone units vary in thickness and lateral extent within a particular hydrostratigraphic zone.

Water levels, or the potentiometric head, from wells completed in the five hydrostratigraphic zones within the Denver Fm were contoured. These contours provide an indication of flow direction. The deepest zone for which sufficient data were available to construct a map was zone 4. The potentiometric surface map of zone 4 indicates flow to the north in Section 24 and flow to the northwest in Sections 22, 23, 26, and 27 (Figure B-30). Hydraulic gradients in this zone range from 0.01 ft/ft in the northern area of Sections 22, 23, 24, and 26, and the northeast portion of Section 27, to 0.003 ft/ft in Section 28 and the southwest portion of Section 27. The flatter gradient is indicative of increased permeability in those sections.

In hydrostratigraphic zone 3, flow is almost due west along the northwest portion of RMA in Sections 22 and 27. Gradients range from 0.013 to 0.02 ft/ft in these sections. In Sections 23 and 24, where flow is to the northwest, gradients range from 0.003 to 0.008 ft/ft (Figure B-31).

Figure 4.2-1 illustrates the generalized flow directions in hydrostratigraphic zone 2. The flow direction in zone 2 is to the north in Sections 23, 24, and 25. The hydraulic

gradient in these sections is approximately 0.006 ft/ft. In the western portion of Section 26 and the eastern portion of Section 27, flow directions are to the west and the gradient is 0.01 ft/ft (Figure B-32).

Hydrostratigraphic zone 1 subcrops in Sections 23 and 24 and is therefore not in contact with the alluvium under either of the boundary containment systems. It is important to the Task 25 study area because it is in contact with overlying zones to the south which have the greatest potential of acting as conduits of contamination. The flow directions within zone 1 are generally toward the northwest in Sections 25, 26, and 24. The hydraulic gradient is 0.01 ft/ft in zone 1 (Figure B-33).

Hydrostratigraphic zone 1u appears just south of the Task 25 study area in the southeast quarter of Section 26 and the southwest quarter of Section 25. Due to the limited extent of zone 1u in the Task 25 area, it is only important in terms of its interaction with the underlying zone 1. The flow direction in zone 1u is to the north in Section 25, but to the northwest in Section 26. Hydraulic gradients range from 0.01 to 0.03 ft/ft in these sections (Figure B-34).

Factors other than material heterogeneity, which reflects K , can affect hydraulic gradient in an aquifer. These would include the cross-sectional area through which flow is moving, and the volume of flow attempting to pass through that area. This would account for gradient changes in those areas where aquifer materials appear to be fairly homogeneous, but yet exhibit varying gradients.

Other information provided by the potentiometric maps is the direction of vertical flow. This assumes total saturation of the formation, or at minimum, direct hydraulic connection between the sand zones. Based on the potentiometric maps it would appear that movement is downward from hydrostratigraphic zones 1u to 4. The differences in potentiometric head between zones 1 and 2 are less in Section 25 and greater in Section 26. Between zones 2 and 3 the differences are minimal in Sections 23 and 24, particularly in the vicinity of the NBCS. In Sections 26 and 27 the

difference in head between zone 2 and 3 may be as great as several feet. Between zones 3 and 4 the head differences are minimal in Sections 26 and 27, but there are more marked differences of several feet or more in Sections 22, 23, and 24 (Figures B-30 through B-34).

Well hydrographs constructed for Denver Fm wells in the Task 25 area indicate some trends. Hydrographs are presented in Figures B-35 through B-67. The majority of the wells upgradient of the NBCS indicate declining water levels from 1981 to 1987. Examples of this are hydrographs for Wells 23181, 23185, 23186, 23187, 23192, and 23193. Wells in the vicinity of First Creek drainage, such as 24120 and 24108, indicate increasing water levels from 1981 to 1986 and stabilized water levels for 1986 and 1987. The water level trends at these wells are probably due to the recharge of the aquifer from First Creek, or possibly due to the influence of the NBCS. Wells immediately upgradient of the NBCS also appear to exhibit a recent decline in water levels, but this is not evident of all the hydrographs. An example of this is the hydrograph from Well 23177.

Upgradient of the NWBCS, the hydrographs from Wells 22030 and 22031 indicate declining water levels. The hydrographs for Wells 27057 and 27058, which are located further upgradient, indicate stable water levels with generally less than a foot of water level fluctuations from quarter to quarter. Hydrographs for upgradient Wells 22023 and 22024 indicate stable water levels since FY86.

4.2.3 AQUIFER PARAMETERS

K and T were estimated for Denver Fm hydrologic units from two pumping tests performed by Black and Veatch (1980, RIC#81266R25) and from 35 slug tests performed by May et al. (1980, RIC#81266R48) and ESE. ESE performed slug tests on 12 Denver Fm monitoring wells installed within the study area. The location of Denver Fm and alluvial aquifer tests are shown in Figure 4.1-6. All of the data collected is in the vicinity of the NBCS. Although the estimation of K and T from a slug test is representative of only the water-bearing material close to the well (Cooper

et al., 1967), slug tests were used for this study to provide order of magnitude estimates for K at a large number of sites.

The values of K and T obtained from the slug test analyses of May et al. (1980, RIC#81266R48) and ESE, are presented in Table 4.2-1. The May et al. (1980, RIC#81266R48) slug test data were reanalyzed and correlated to ESE data for comparative purposes. Close agreement exists between the results of the two studies.

A wide distribution of K and T values resulted from the different wells tested. The heterogeneous anisotropic nature of the Denver Fm sandstone units near the NBCS is believed to be responsible for varying results. The values for K and T are reported by sand zones. A correlation between NBCS units and regional zones is provided in Table 4.2-2. Test data were not available for zone 1u. However, data for zones 3 and 4 were obtained in addition to data for zone 2 (Table 4.2-1).

Values of T for sand zone 2 range from 0.160 to 66.5 gpd/ft and K values range from 0.041 to 4.9 gpd/ft². The minimum K value was measured in a test corresponding to Well 23227 which is located upgradient of the NBCS and is screened in silty sandstone. The maximum K value corresponds to Well 23226 which is located downgradient of the NBCS and screened in fine- to coarse-grained sandstone. Higher K values are indicative of flood basin deposits, which typically exhibit coarsening sequences upwards. Coarser-grained materials with higher permeabilities occur at the top of the deposits.

The results of the slug tests conducted at Well 23226 are of the same order of magnitude as the nearby pumping test conducted in zone 2 at Well 23176 by Black and Veatch (1980, RIC#81266R25). The average K value determined by Black and Veatch was 12 gpd/ft² and the average T value was 200 gpd/ft. Reanalysis of the pumping test data using the Jacob method for late drawdown data give an average K value of about 12 gpd/ft² and an average T value of 206 gpd/ft. Black and Veatch

Table 4.2-1. Slug Test Results for Denver Pm Units in the Tank 25 Study Area

Site Number	Well Number	Screen Interval (ft)	Hydraulic Conductivity* (gpd/ft ²)				Aquifer Thickness (ft)	Transmissivity (gpd/ft)		Reference
			Slug In	Slug Out	Slug In	Slug Out		Slug In	Slug Out	
NE#1A	E-27	33.25-39.00	0.041	0.045	1.9	2.10	4.0	0.163	0.179	ESE, 1988
	E-28	24.98-36.67	4.9	4.5	229.0	214.0	13.67	66.47	61.88	ESE, 1988
	E-32	47.3-58.00	0.051	0.050	2.4	2.4	8.0	0.41	0.40	ESE, 1988
	E-33	31.1-44.00	1.9	1.0	91.6	48.0	11.0	21.4	11.21	ESE, 1988
	979	51.0-46.0	—	0.038	—	14.5	13.0	—	4.10	May, 1980
	981	41.0-45.0	—	0.60	—	28.5	4.0	—	2.41	May, 1980
	977	46.0-50.0	—	0.34	—	16.2	4.0	—	1.38	May, 1980
	885	42.0-34.0	—	1.7	—	80.7	10.0	—	17.1	May, 1980
	991	47.0-52.0	—	0.56	—	26.2	3.0	—	1.67	May, 1980
	E-32	63.26-74.00	0.59	0.42	27.7	19.7	10.74	6.30	4.49	ESE, 1988
NE#2	E-63	40.12-46.00	4.9	4.5	231	210	7.0	34.2	21.21	ESE, 1988
	E-38	39.26-55.50	4.6	4.8	218	227	16.24	74.8	77.89	ESE, 1988
	978	64.0-74.0	—	0.37	—	17.3	7.0	—	2.80	May, 1980
	976	48.0-53.0	—	1.67	—	78.8	3.0	—	5.01	May, 1980
	975	61.0-66.5	—	0.52	—	24.3	5.5	—	2.84	May, 1980
	963	60.0-65.0	—	0.16	—	7.61	5.0	—	0.81	May, 1980
	979	81.0-100.0	—	.10	—	4.76	19.0	—	0.835	May, 1980
	981	70.0-77.0	—	1.3	—	62.5	7.0	—	1.45	May, 1980
	977	70.0-88.0	—	10.21	—	9.9	18.0	—	23.9	May, 1980
	991	68.0-75.0	—	3.5	—	166.0	7.0	—	24.62	May, 1980
NE#3	E-38	64.29-75.00	0.51	0.13	24.2	61.7	14.0	7.18	1.83	ESE, 1988
	E-39	69.78-86.00	0.90	0.69	42.7	32.6	16.22	14.7	11.2	ESE, 1988
	E-40	61.50-88.50	2.7	2.3	126	108	28.0	74.8	64.1	ESE, 1988
	978	105.0-110.0	—	0.19	—	9.19	5.0	—	0.97	May, 1980
	991	85.0-103.0	—	0.64	—	30.1	18.0	—	11.47	May, 1980
	855-991	80.0-90.0	—	0.014	—	0.66	10.0	—	0.14	May, 1980
	979	31.0-35.0	—	256	—	12100	4.0	—	1022.25	May, 1980
	983	25.0-30.0	—	2.8	—	131	5.0	—	13.84	May, 1980
	E-34	40.30-51.00	2.9	2.3	138	109	12.0	35.19	27.61	ESE, 1988
	986	52.0-62.0	—	0.30	—	14.2	10.0	—	3.01	May, 1980
NE#4	987	75.0-90.0	—	4.3	—	202	14.0	—	59.8	May, 1980
	984	45.0-53.0	—	1.2	—	58.6	8.0	—	9.94	May, 1980
	985	40.0-58.0	—	8.9	—	419.0	18.0	—	159.94	May, 1980
	984	70.0-80.0	—	0.58	—	27.2	6.5	—	37.41	May, 1980
	E-39**	36.7-42.66	4.2	4.5	199	212	5.88	24.75	26.39	ESE, 1988

* Hydraulic conductivity value, for May 1980 results estimated by dividing screened aquifer thickness into transmissivity.

Table 4.2-2. Water Elevations For Well Cluster Sites in The Vicinity of NBGS
(Page 1 of 2)

Well Number	Hydro- Stratigraphic Zone*	Equivalent Task 36 Hydrostrati- graphic Unit	Water Elevations by Sampling Quarter FY87			
			1st	2nd	3rd	4th
23122	All	All				
23227	2	NBW#1A	***	***	***	***
23228	3	NBW#1	***	***	***	***

23123	All	All				
23233	2	NBW#1A	***	***	***	***
23234	3	NBW#1	***	***	***	***

**		All			5138.2	5137.3
23178	Shale	Shale above 1A	5136.2	5137.1	5136.6	5136.4
23176	2	NBW#1A	5135.5	5135.7	5135.9	5135.2
23177	2	NBW#1	5135.2	5135.4	5135.7	5135.0

**		All			5140	5140.2
24135	2	NBE#1	5138.3	5139.1	5139.4	5138.8
24136	3	NBW#1	5138.0	5138.9	5139.3	5138.5
24137	4	NBW#2	***	5137.5	5137.3	5137.3

23217	All	All	ND	ND	5132.5	5132.5
23204	2	NBW#1A	5132.2	5132.1	5132.5	5132.2

23235	2,3	NBW#1A	***	***	***	***

23226	2	NBW#1A	***	***	***	***
23236	2,3	NBW#2	***	***	***	***

23043	All	All	5130.7	5130.9	5131.0	5130.8
23218	2	NBW#1	***	***	5129.7**	5129.5
23219	3	NBW#2	***	***	5128.7**	5128.5

23215	All	All			5131.2	5130.4
23200	3	NBW#2	***	***	5129.1**	5128.9
23201	4	NBW#3	***	***	5129.1**	5128.8

**		All			5134.0	5134.0
24191	2	NBW#1	***	***	5132.4**	5131.5

**		All			5136.5	5136.5
24171	3	NBE#2	5130.0	5128.7	5128.5	5126.6
24172	5	NBE#4	5136.3	5136.8	5137.1	5135.6

Table 4.2-2. Water Elevations For Well Cluster Sites in The Vicinity of NBCS
(Page 2 of 2)

Well Number	Hydro-Stratigraphic Unit*	Equivalent Task 36 Hydrostratigraphic Unit	Water Elevations by Sampling Quarter FY87			
			1st	2nd	3rd	4th
24176	All	All	***	5133.0	5135.3	5132.5
24174	3	NBE#2	5131.1	5132.2	5133.87	5132.5
24175	4	NBE#3	5131.3	5132.4	5135.0	5132.7
37338	All	All	5126.0	5126.6	5129.7	5126.7
37376	3	NBE#2	***	5129.8	5129.8	5128.6
37370	All	All	***	5109.6	5110.4	5108.5
37371	3	NBW#2	***	5109.6	5110	5108.2
37372	4	NBW#3	***	5109.2	5109.1	5108.3
37374	All	All	***	***	5108.9	5108.6
37379	3	NBW#2	***	***	5107.3	5106.7
37380	4	NBW#3	***	5106.8	5106.5	
**		All	***	***	Dry	Dry
37387	*	*	***	***	5119.6	5120.1
37388	4	NBW#3	***	***	5108.8	5109.5
37389	All	All	***	***	***	5123.0
37390	3	NBW#2	***	***	***	5122.4

- * All - Represents either alluvial well or data from appropriate water table map.
 ** Elevation value interpolated from water table contour map for sampling period.
 *** Well not installed at the time of this sampling period.
 * Unable to correlate to sandstone unit.
 ** Water level measured later in quarter.

Source: ESE, 1988

stated that this test location is in a very complex geologic area that can create boundary effects obscuring the test results. Test results may be suspect due to these boundary conditions.

T values in zone 3 range from 3.0 to 160 gpd/ft. K values range from 0.30 to 8.9 gpd/ft² with a mean value of 3.3 gpd/ft². The lowest K values were obtained in Wells 24142 and 24146. These wells are screened in silty sandstones on the margins of a main channel for zone 3. The highest value was obtained from a test performed on Well 24144. This well is screened over much of the aquifer near the middle of the channel. Well 24144 is located approximately 100 ft south of Well 24145 which was used by Black and Veatch to conduct a 24-hour pumping test (1981). The average K value obtained by Black and Veatch was 8.3 gpd/ft². This value corresponds very closely with the value obtained by May *et al.* (1980, RIC#81266R48) from the slug test data for Well 24144.

The T values for zone 4 range from 0.14 to 74.8 gpd/ft. K values range from 0.01 to 2.7 gpd/ft². The lowest K value in zone 4 corresponds to a slug test performed in Well 23164. This well is located downgradient of the barrier about 2,500 ft west of D Street. The low K value is attributable to the fact that the well is screened in sandstone and clayey sandstone flood basin deposits distal to the main meander belt sands of zone 4.

4.2.4 FLOW DIRECTIONS AND RATES

Flow directions have been discussed in Section 4.2.2 in conjunction with a discussion of the potentiometric head. Flow rates are discussed here on the basis of data generated in Section 4.2.3. The average low K for approximate equivalent zones 2, 3, and 4 was 0.15 gpd/ft² and the average high was 5.5 gpd/ft². Porosity within the Denver Fm sands ranged from 33 to 43 percent. Using the lower porosity value and the higher K value in calculations of travel time, a conservative estimate for flow to move from Basin F to the north boundary would be greater than 700 years. This indicates that in most areas contaminants are moving through the alluvium and then

entering the Denver Fm sand zones some distance from the contaminant source areas. If the estimates were in error by an order of magnitude, this would still be the case.

4.2.5 DISCHARGE

Water moving through the Denver Fm is discharged from the aquifer in two ways, through dewatering wells pumping from the formation, and locally as recharge to the alluvial materials. Neither mechanism is a significant factor on or in the vicinity of RMA. However, there are indications that recharge to the alluvium is occurring offpost north of the NBCS and in localized subcrops upgradient of the boundaries.

4.2.6 AQUIFER INTERACTIONS

Local interactions between the alluvium and Denver Fm aquifers are means by which the Denver Fm can potentially become contaminated. Understanding the potential for intraformational vertical ground-water movement between Denver Fm sandstone units is important for assessing the potential for vertical contaminant migration within the Denver Fm. Water-level data obtained during the study and presented in Tables 4.2-2 and 4.2-3 have been used to assess aquifer interactions and are discussed in the following sections.

Hydrographs constructed for alluvium and Denver Fm wells in the Task 25 area demonstrate hydrologic interaction between the alluvium and Denver Fm, as well as within zones of the Denver Fm. Cluster Wells 24158 and 24159 are screened in the alluvium and hydrostratigraphic zone 1, respectively. These wells exhibit great similarity of water level fluctuations. Cluster Wells 23185, 23186, and 23187 are screened in hydrostratigraphic zones 1, 2, and 4, respectively. Water levels in these hydrostratigraphic zones exhibit many of the same seasonal water level fluctuations.

4.2.6.1 Alluvial Aquifer and Denver Fm Sandstone Unit Interactions

The potential for vertical ground-water movement between the alluvial aquifer and the Denver Fm was assessed by evaluating differences in water elevations of clustered wells constructed in both aquifers. At locations near NBCS where there were no

Table 4.2-3. Water Elevations For Well Cluster Sites in The Vicinity of NWBCS

Well Number	Hydro- Stratigraphic Zone	Water Elevations by Sampling Quarter FY87*			
		1st	2nd	3rd	4th
22022	All	5093.5	5093.0	5093.4	5093.3
22023	4	5091.8	5091.5	5091.5	5091.9
22024	5	5091.8	5091.5	5091.7	5091.8
22029	All	Dry	Dry	Dry	Dry
22030	4	5099.6	5099.7	5099.2	5099.5
22031	5	5097.5	5097.7	5096.2	5097.2
22025	All	Dry	Dry	Dry	ND
22027	3	5108.4	5108.6	5108.6	5108.6
22028	4	5102.5	5102.5	5102.2	5102.1
23185	1 (in shale)	5142.8	5142.9	5142.9	5142.7
23186	2	5129.1	5129.0	5129.0	5128.7
23187	4	5120.7	5120.7	5120.7	5120.4
27059	All	Dry	Dry	Dry	Dry
27060	2	ND	ND	ND	5127.1
27061	5	ND	ND	Dry	Dry
27056	All	Dry	Dry	Dry	Dry
27057	3	5098.6	5098.3	5098.4	5098.6
27058	4	5098.2	5098.4	5098.6	5098.3
27053	All	5102.7	5102.8	5103.2	5102.8
27054	4	5098.4	5100.5	ND	5101.2
27055	5	5097.7	5097.8	5097.8	ND

*ND - No data collected

Source: ESE, 1988

alluvial wells within 100 ft of a Denver Fm well, the water-table elevation was estimated from the alluvial aquifer water-table map. This is considered a good approximation of the water-table elevation due to close well spacing in the alluvial aquifer in the vicinity of NBCS.

Lower water-level elevations in wells screened within Denver Fm units compared to elevations in the alluvial aquifer indicate a potential for the downward movement of water. Higher potentiometric levels in the Denver Fm units compared to elevations in the alluvial aquifer indicate a potential for upward movement.

Upgradient of the soil-bentonite barrier, the water-table elevation in the alluvial aquifer is higher than the potentiometric surface elevations of the upper units of the Denver Fm. Approximately 500 ft upgradient of the pilot portion of the soil-bentonite barrier, the downward vertical gradient between the alluvial aquifer and the Denver Fm averages 0.07 ft/ft. Immediately upgradient of the pilot portion of the soil-bentonite barrier, a downward vertical gradient of approximately 0.12 ft/ft is observed at a cluster site near the barrier. These downward gradients could vary significantly near the soil-bentonite barrier due to the influences on potentiometric head by the barrier.

Immediately downgradient of the pilot portion of soil-bentonite barrier, the potentiometric surface of zone 2 begins to merge with the water table of the alluvial aquifer. In some instances, the zone 2 potentiometric surface appears to be coincident with the water table, and, in some cases, it appears to exhibit a higher potentiometric surface elevation. A higher potentiometric elevation in this unit may occur upgradient of the actual geologic subcrop of the unit due to low alluvial water-table conditions caused by inadequate NBCS recharge.

Downward gradients between the alluvial aquifer and the upper Denver Fm units were also observed several hundred feet offpost between alluvial We's 37374 and 37389 and their respective Denver Wells 37379 and 37390. These cluster sites are

located about 1,000 ft north of 96th Avenue in Section 14. A slight upward vertical gradient exists between offpost alluvial Well 37370 and Denver Fm Well 37371. Well 37371 is screened in a subcropping Denver Fm sandstone.

Upgradient of the northeast end of the NWBCS there is a downward vertical gradient, from the alluvium to the Denver Fm, between Cluster Wells 22029 and 22030. Downgradient of the southwest end of the NWBCS there is a downward gradient at Cluster Wells 22022 and 22023. South of the NWBCS in Section 27, there is a downward vertical gradient between Cluster Wells 27053 and 27054 (Table 4.2-3).

4.2.6.2 Denver Fm Sandstone Units Interactions

Near the NBCS, vertical gradients are generally downward between adjacent Denver Fm units. This implies that ground water within the upper Denver Fm sandstones in this area has the tendency to flow to lower units before ultimately discharging to the alluvium near subcrop areas. This potential for vertical ground-water movement between Denver Fm sandstone units was assessed by evaluating differences in water elevations between clustered wells constructed in adjacent sandstone units.

Upgradient of the NBCS, vertical gradients are generally downward between adjacent Denver Fm sandstone units. Downward vertical gradients have been observed between hydrostratigraphic zones 2 and 3 upgradient of the system. Approximately 500 ft upgradient of the soil-bentonite barrier, the downward vertical gradient between hydrostratigraphic zones 2 and 3 is about 0.05 ft/ft.

About 350 ft downgradient of the soil-bentonite barrier and just west of D Street, a downward vertical gradient of 0.22 ft/ft has been observed between Wells 23218 and 23219. These two wells are screened in hydrostratigraphic zones 2 and 3, respectively.

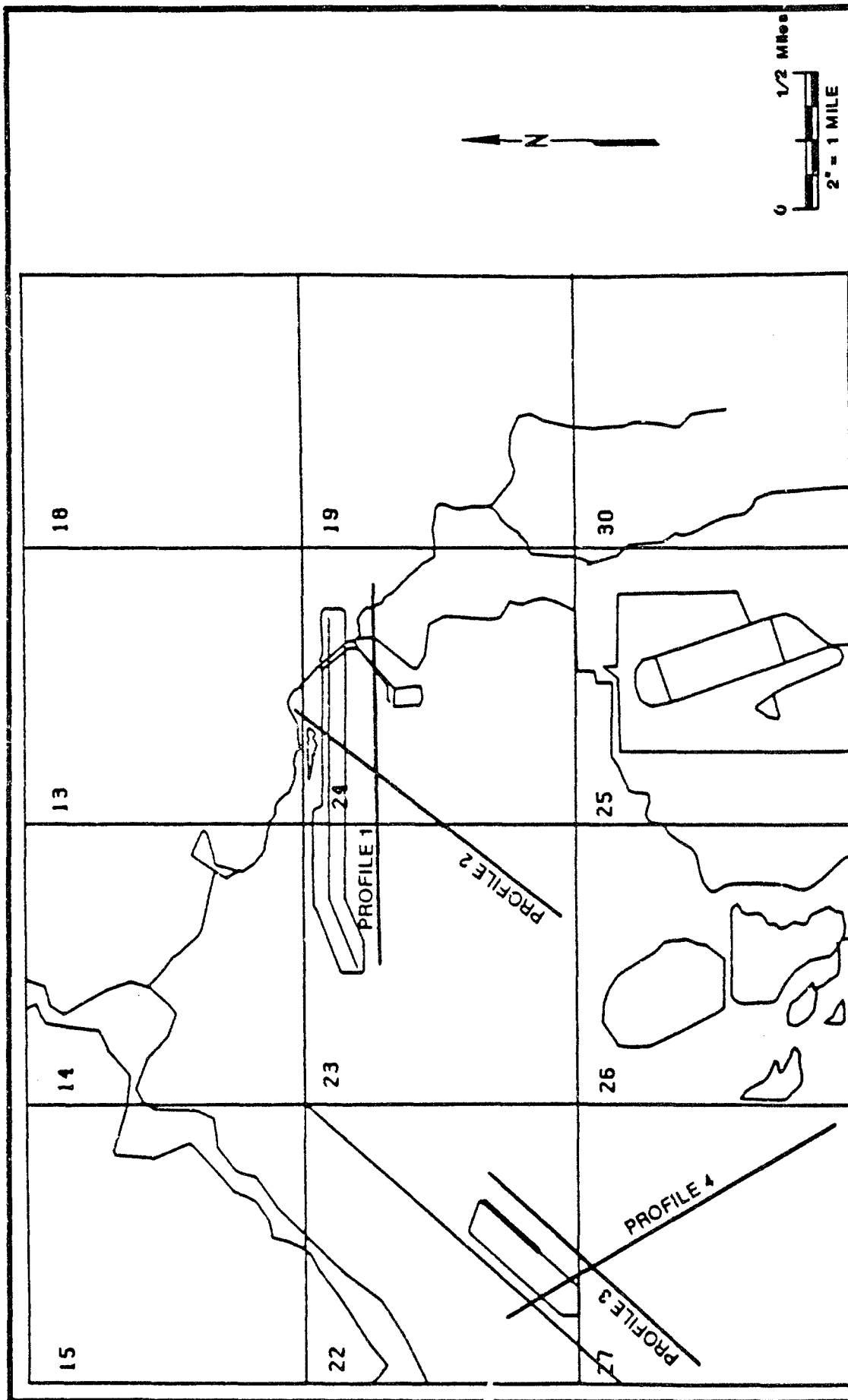
Downward gradients between Denver Fm units are also observed several hundred feet offpost. At Cluster Wells 37371 and 37372 (located approximately 1,000 ft north of 96th Avenue in Section 14), downward gradients averaging 0.05 ft/ft have been noted.

These wells are screened in zones 3 and 4, respectively. In the same vicinity, there is also an apparent downward gradient of 0.05 ft/ft between Well 37379 (zone 3) and Well 37380 (zone 4).

Upgradient of the NWBCS there is a net downward vertical gradient observed between Wells 23186 and 23187, which are screened in zones 2 and 4, respectively. There is no zone 3 screen in this cluster. There is also a downward vertical gradient observed between Wells 27060 and 27061, which are screened in zones 2 and 5, respectively. There is no zone 4 screen in this cluster. There is a slight downward vertical gradient of 0.02 ft/ft observed between Wells 27057 and 27058. These wells are screened in zones 3 and 4, respectively.

Upgradient of the northeast end of the NWBCS, a downward vertical gradient of 0.35 ft/ft was observed between Wells 22030 and 22031. These wells are screened in hydrostratigraphic zones 4 and 5, respectively. A downward vertical gradient of 0.23 ft/ft was also observed between Wells 22027 and 22028, which are upgradient of the NWBCS. These wells are screened in hydrostratigraphic zones 3 and 4, respectively. South of the NWBCS, a downward vertical gradient of 0.03 ft/ft was observed between Wells 27054 and 27055. These wells are screened in hydrostratigraphic zones 4 and 5, respectively.

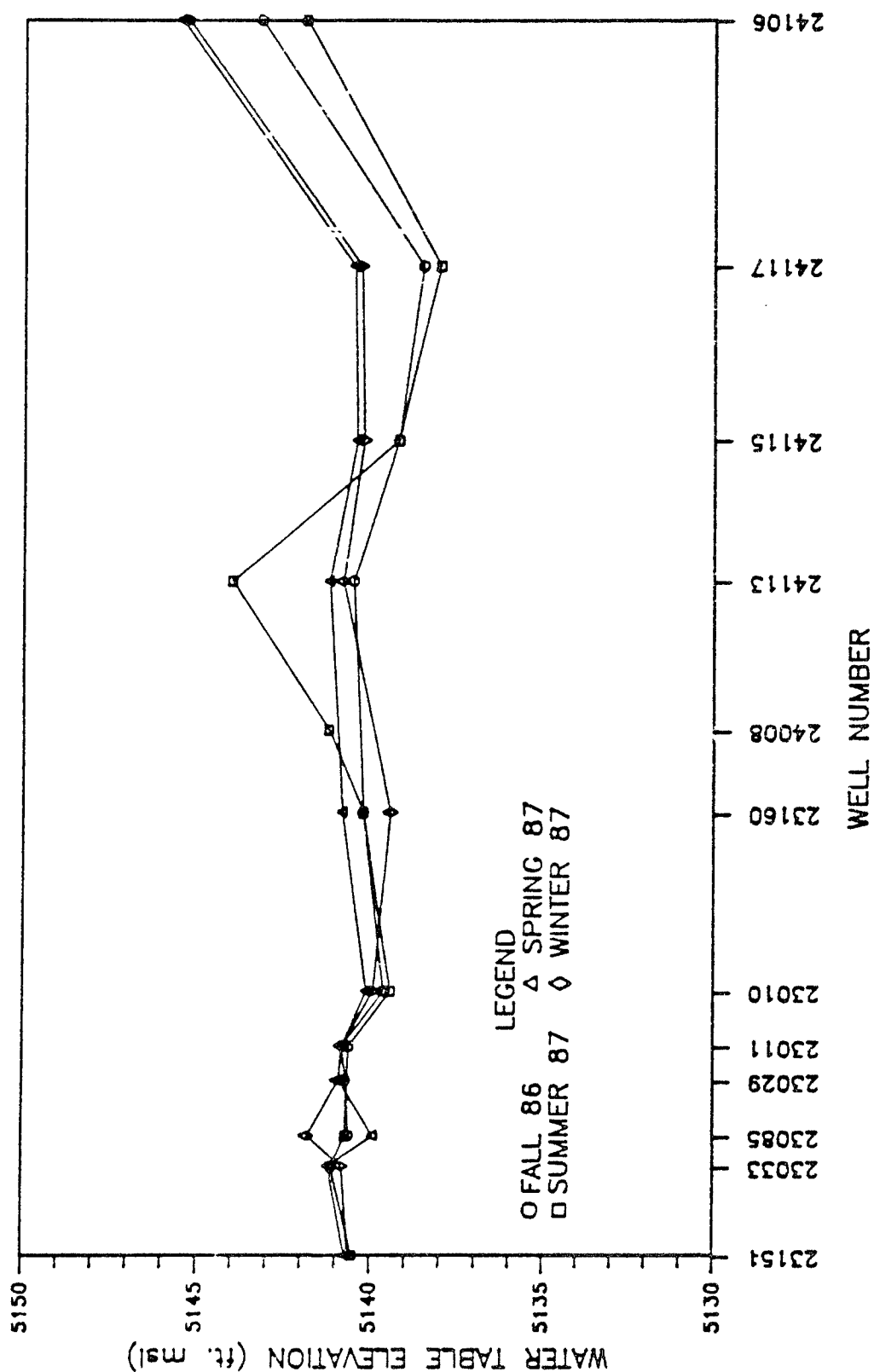
Downgradient of the southwest end of the NWBCS, the water levels observed in Wells 22023 and 22024 appear to be coincident. These wells are screened in hydrostratigraphic zones 4 and 5, respectively.



Prepared for:
 U.S. Army Program Manager's Office
 For Rocky Mountain Arsenal
 Aberdeen Proving Ground, Maryland

Figure 4.1-1
 LOCATION MAP FOR HYDROGRAPHIC PROFILES

SOURCE: ESE, 1968



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 For Rocky Mountain Arsenal
 Aberdeen Proving Ground, Maryland

Figure 4.1-2
 GROUND-WATER ELEVATIONS ALONG PROFILE 1

SOURCE: ESE, 1988

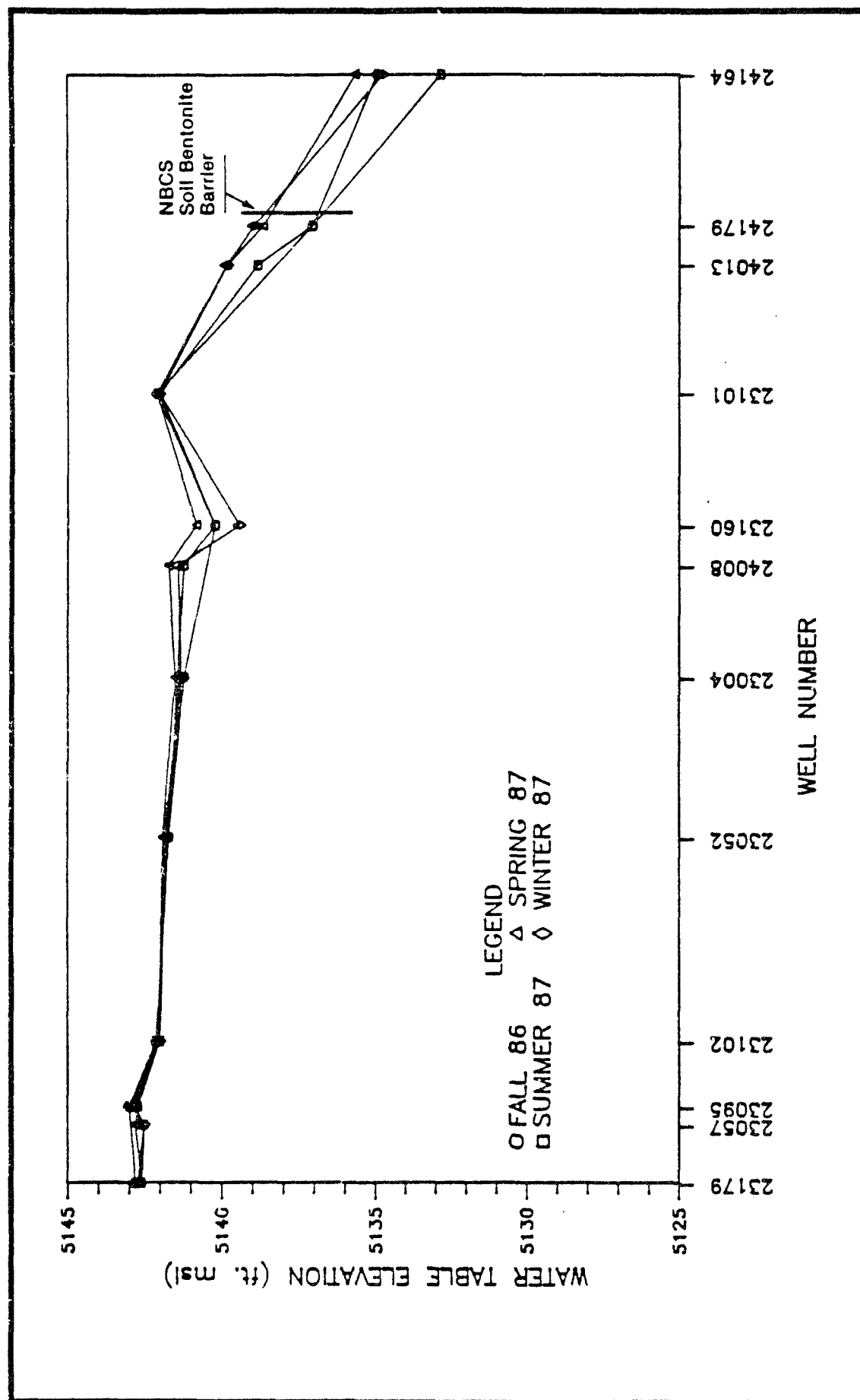
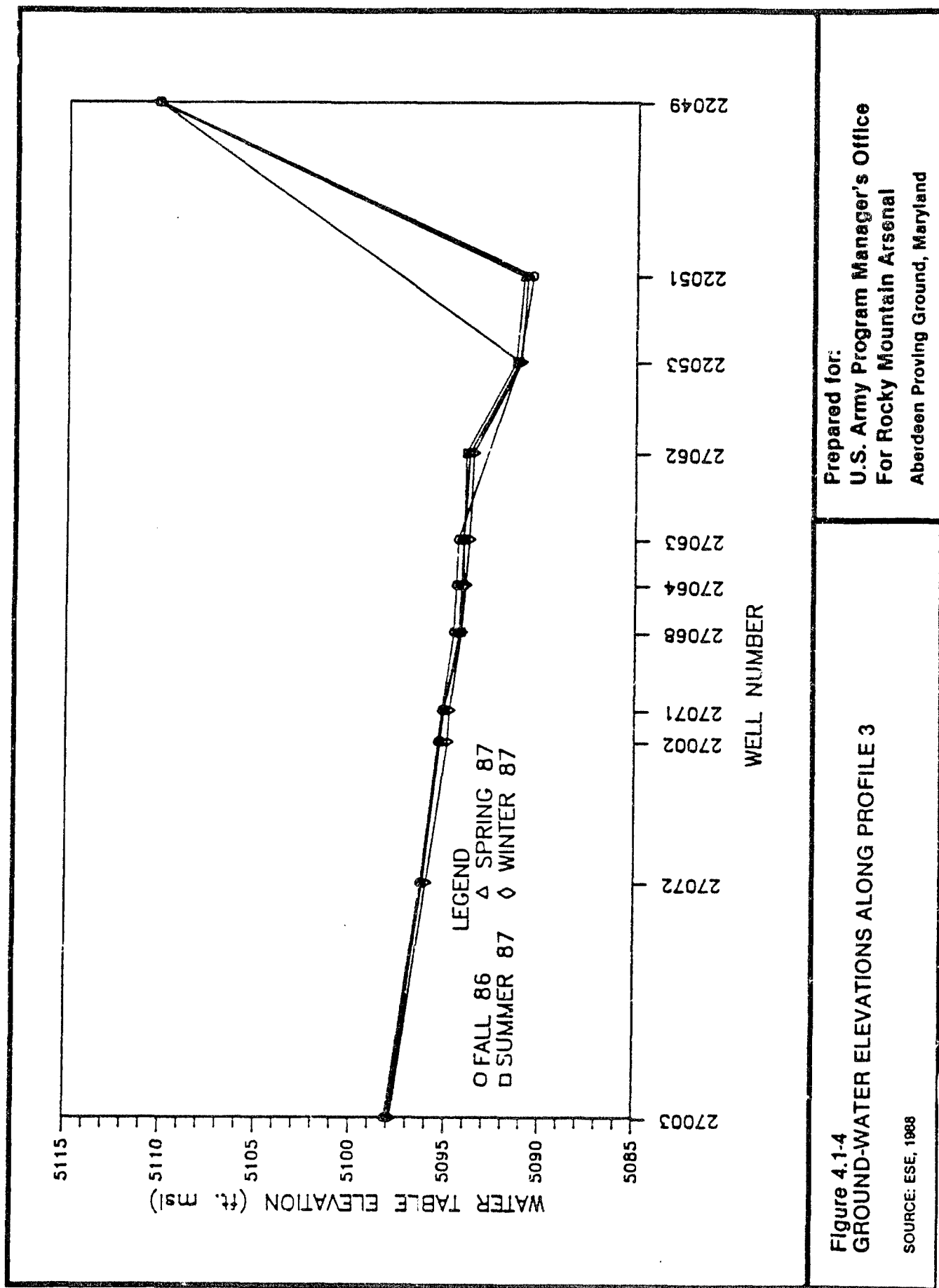


Figure 4.1-3
GROUND-WATER ELEVATIONS ALONG PROFILE 2

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 Aberdeen Proving Ground, Maryland

SOURCE: ESE, 1986



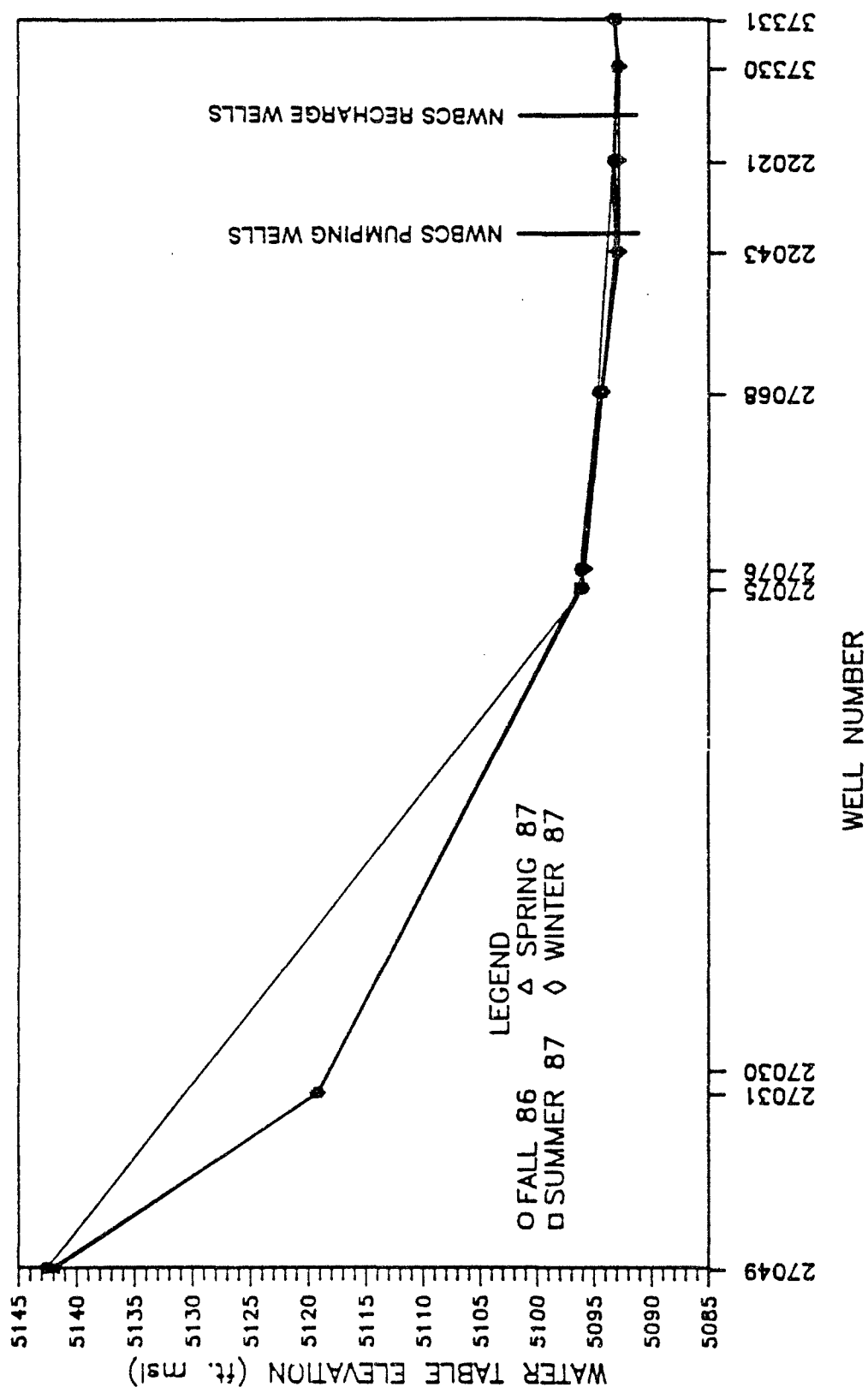


Figure 4.1-5
GROUND-WATER ELEVATIONS ALONG PROFILE 4

SOURCE: ESE, 1983

Prepared for:
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For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

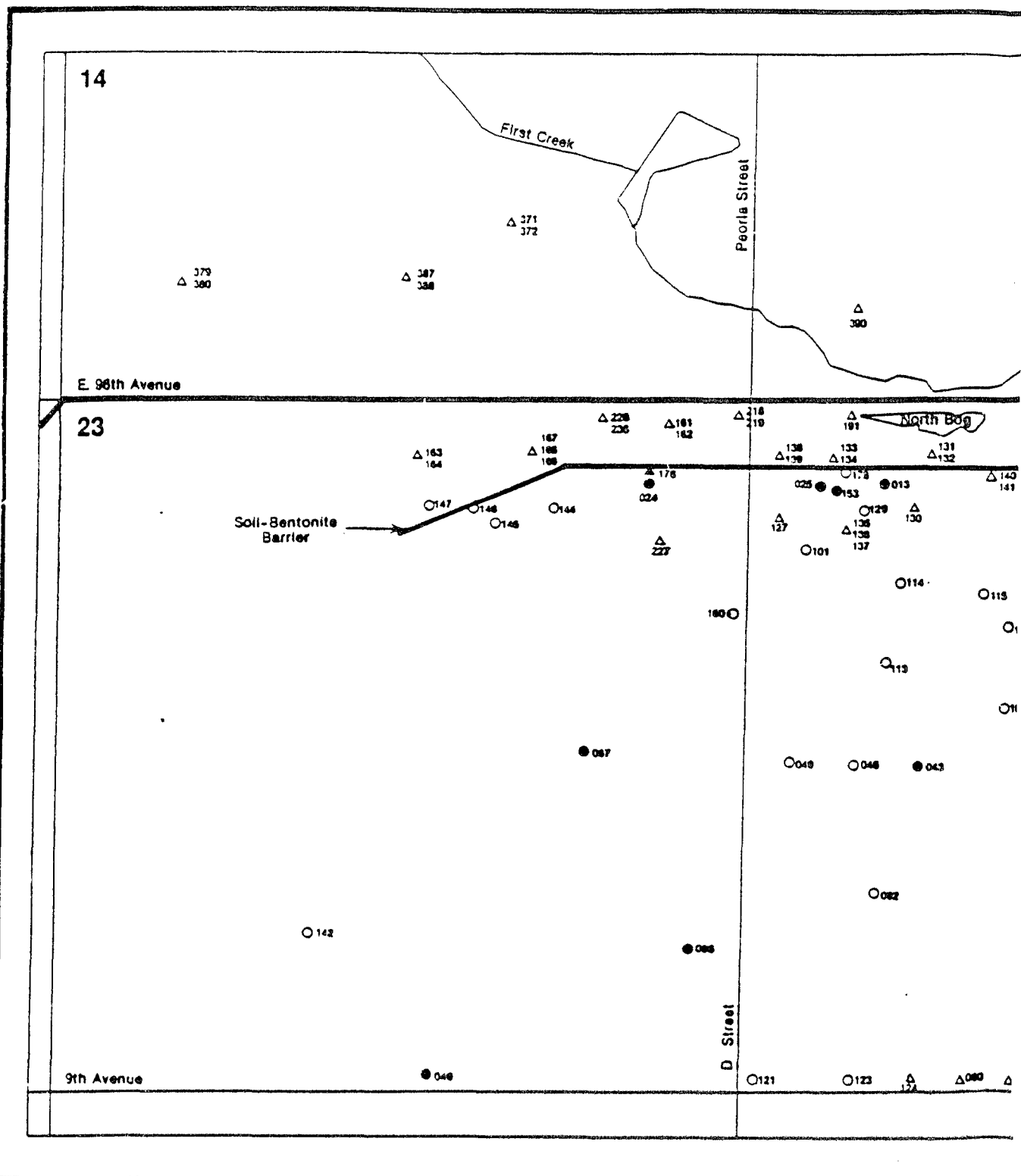
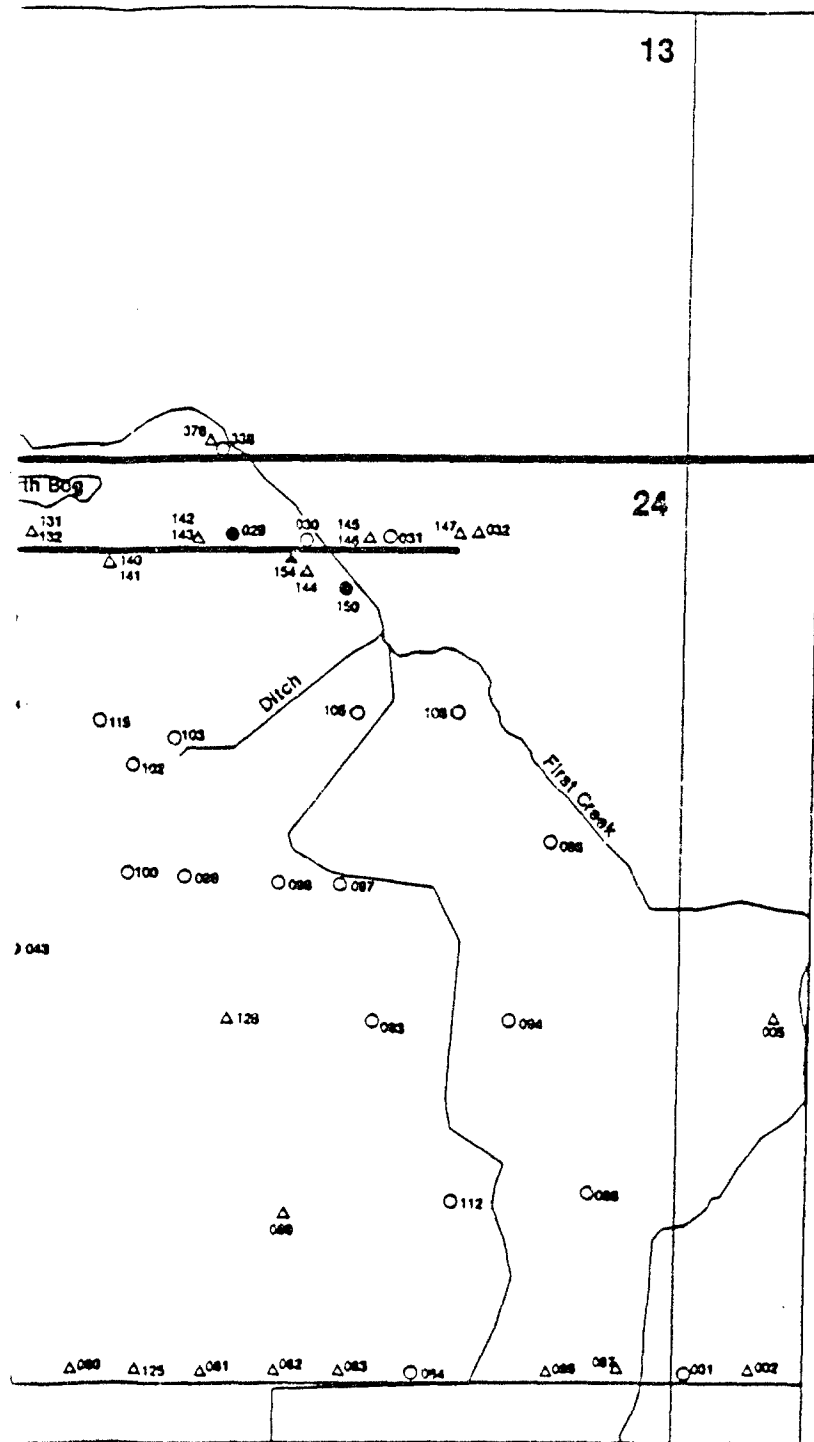
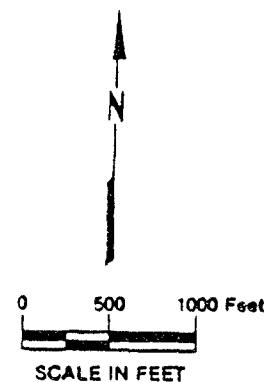


Figure 4.1-6
 LOCATION MAP OF AQUIFER TESTS PERFORMED IN THE
 TASK 25 STUDY AREA
 SOURCE: ESE, 1988



EXPLANATION

- Alluvial Slug Test
- Alluvial Pumping Test
- △ Denver Slug Test
- ▲ Denver Pumping Test



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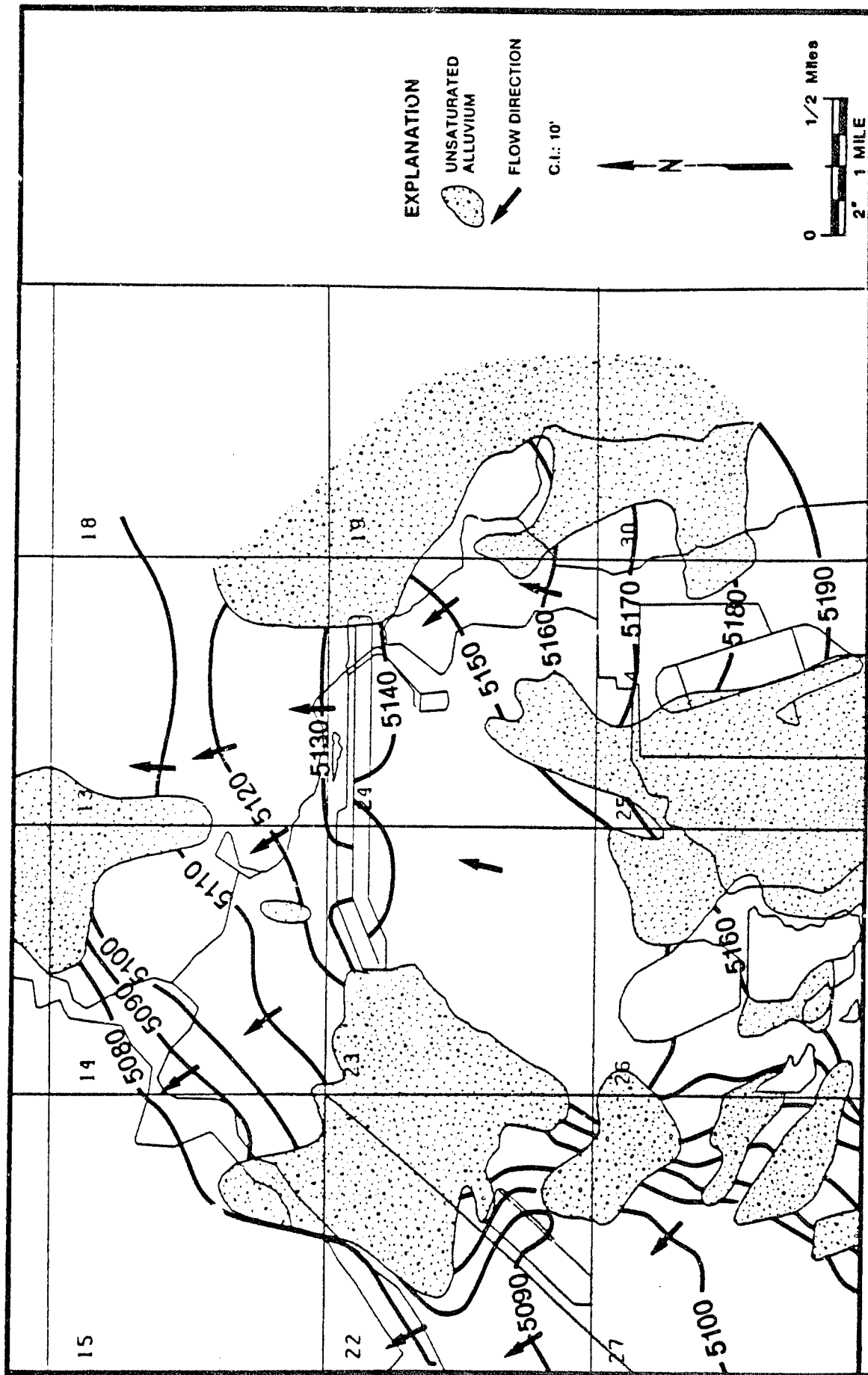
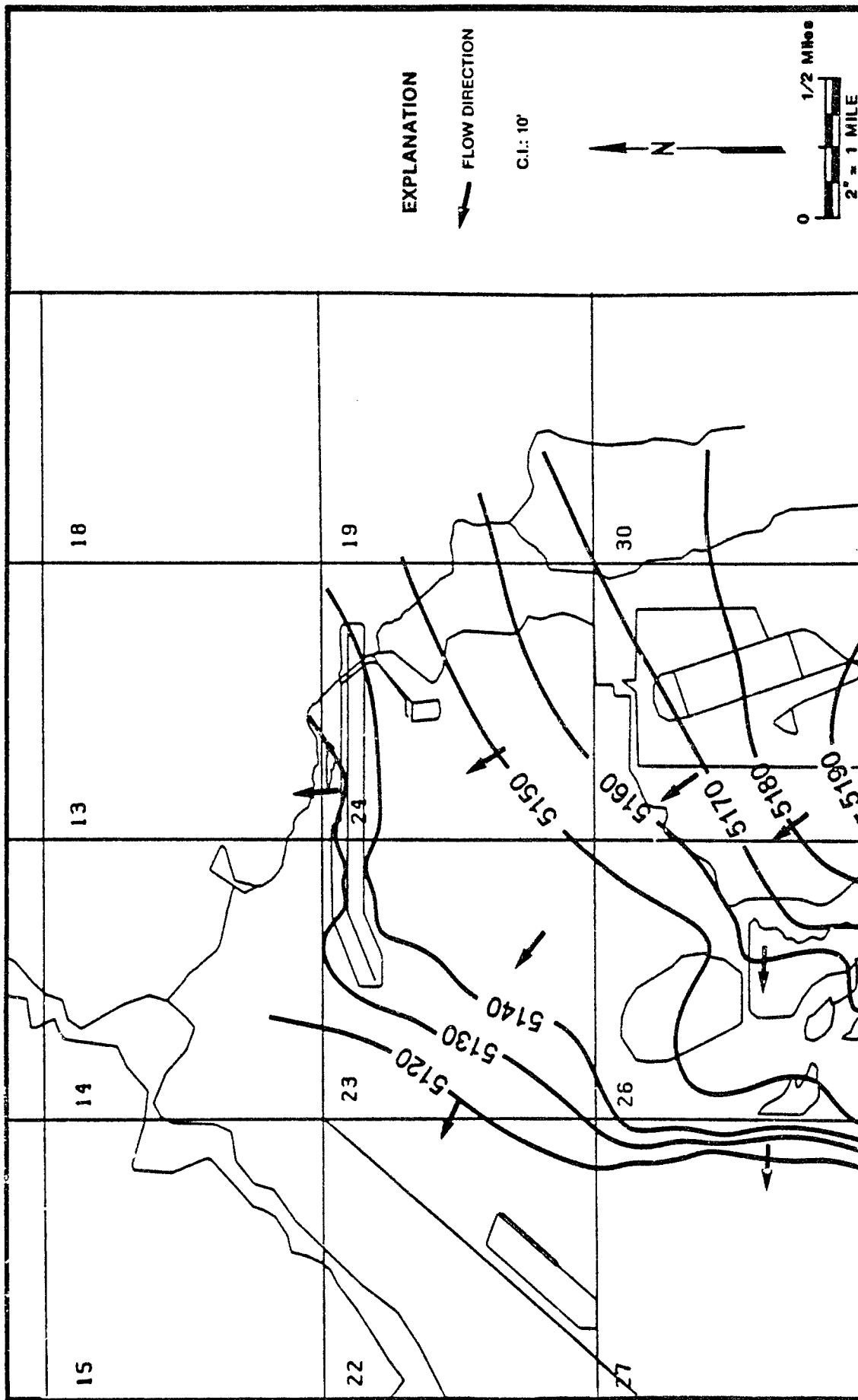


Figure 4.1-7
GENERALIZED ALLUVIAL FLOW DIRECTIONS
ALLUVIAL POTENTIOMETRIC SURFACE
SOURCE: ESE, 1988

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Figure 4.2-1
GENERALIZED DENVER FLOW DIRECTIONS
SAND 2 POTENTIOMETRIC SURFACE

SOURCE: ESE, 1988

5.0 GROUND-WATER CONTAMINATION

Task 25 conducted ground-water quality monitoring of the alluvium and Denver Fm during FY87. The monitoring networks for the Task 25 study area are described in Section 2.1. Well locations for the alluvium and Denver Fm monitoring networks are presented in Figures B-24A and B-24B. Methods used for analysis of ground water samples are presented in Section 2.2.3. Results of the chemical analyses are tabulated by well number in Appendix A.

Samples were collected under Task 25 for each of the four quarters of FY87; fall 1986 through summer 1987. Other RMA programs that collected ground-water quality samples in the study area during FY87 include Tasks 44, 36, and 39. Interpretations presented in this report incorporate all data collected in the Task 25 study area. This section of the report presents a summary of the concentrations and distributions of target analytes detected in the Task 25 study area. The discussion is presented by aquifer, with the alluvial aquifer water quality presented first. A discussion of the Denver Fm follows.

5.1 NATURE AND EXTENT OF ALLUVIAL AQUIFER CONTAMINATION

The nature and extent of alluvial aquifer contamination in the vicinity of the NBCS and the NWBCS has been investigated during the several years prior to the initiation of Task 25. Localized studies have been performed and results presented in Operational Assessment Reports (Thompson et al., 1985, RIC#86078R01; PMSO, 1987a, RIC#87320R01 and 1987b, RIC#88054R01). These studies evaluated the concentrations and distributions of contaminants near the boundary treatment/containment systems, but were limited in the number of contaminants evaluated: DIMP, DBCP, DCPD (NBCS only), combined organosulfur compounds (NBCS only), endrin, aldrin, dieldrin, chloride, and fluoride. Within the last few years, regional studies have been conducted which included an expanded list of analytes (ESE, 1987b, RIC#87253R01). Although these studies evaluated many more analytes, they did not incorporate the high density of wells in the vicinity of the NBCS

and the NWBCS that the Operational Assessment Studies did. Task 25 presents an evaluation of alluvial aquifer contamination that utilizes the density of wells necessary for a localized assessment, as well as the expanded analyte list resulting from the regional studies. The evaluation of alluvial contamination presented in this report further delineates the concentrations and distributions of contaminants historically investigated, as well as presenting an assessment of analytes not previously evaluated in the Operational Assessment Reports.

5.1.1 DATA PRESENTATION

The data and discussion presented in this section of the report characterize the distribution of target analytes in the alluvial aquifer near the NBCS and the NWBCS. A listing of the frequency of detection for target analytes for the four quarters of FY87 is presented in Table 5.1-1. The wells sampled in each quarter are presented in Table A-1.

Ground-water quality contaminant distribution maps have been prepared for each quarter of FY87 in order to characterize the distribution of target analytes. The initial step in map preparation was plotting analyte concentration values on monitoring well location maps. These values were then hand contoured employing available geologic and hydrogeologic descriptions of the alluvium, including: bedrock configuration and locations of paleochannels; sediment grain size distribution; ground-water flow directions and hydraulic gradient; and saturated thickness and transmissivity. In addition, the operational assessments of the NBCS and the NWBCS were used to adjust contour lines in the vicinity of the boundary systems. These assessments included pumping and recharge rates, as well as chemical analyses of samples collected from withdrawal wells during the fourth quarter FY87.

The contaminant distribution maps use isoconcentration lines to delineate areas of similar contaminant concentration. Isoconcentration lines encompass areas where concentrations exceed the certified reporting limits (CRL). Individual monitoring

Table 5.1-1. Summary of Alluvial and Alluvial/Denver Analyte Detections

COMPOUND	FA86 ALL.	FA86 A/D	WI87 ALL.	WI87 A/D	SP87 ALL.	SP87 A/D	SU87 ALL.	SU87 A/D
CL6CF	2	0	5	0	0	0	1	0
ALDRN	8	0	1	0	1	0	5	0
ISODR	3	0	1	0	1	0	1	0
PPDDE	1	0	1	0	5	0	1	0
CLDAN	0	0	0	0	1	0	0	0
DLDRN	90	3	70	2	85	3	88	2
ENDRN	25	0	14	0	33	0	31	2
PPDDT	1	0	1	0	2	0	6	1
DCPD	17	0	16	1	22	2	23	1
MIBK	1	0	1	0	0	1	1	0
DBCP	32	0	32	0	36	2	34	1
DMMP	4	0	1	0	1	1	0	0
DIMP	97	3	71	4	85	5	88	4
DMDS	2	0	2	0	2	1	3	0
BTZ	0	0	5	1	10	0	4	2
OXAT	29	2	29	2	29	3	28	2
DITH	33	2	30	2	38	3	29	2
CPMS	18	0	16	0	23	2	23	0
CPMSO	44	1	19	1	36	3	32	2
CPMSO2	43	1	39	1	50	3	50	3
C6H6	8	0	6	0	18	1	14	0
MEC6H5	7	0	3	0	2	0	1	0
ETC6H5	2	0	2	0	2	1	5	1
MXYLEN	2	0	1	0	1	1	1	0
XYLEN	1	0	1	0	3	0	1	0
CH2CL2	18	1	5	0	2	0	5	0
11DCE	7	0	0	1	0	1	0	0
11DCLE	3	0	3	1	1	1	2	0
T12DCE	3	0	0	0	0	1	1	0
CHCL3	72	1	63	1	69	4	69	2
12DCLE	21	1	18	1	20	1	21	1
111TCE	1	0	3	0	2	0	0	0
CCL4	8	1	10	1	7	0	6	0
TRCLE	28	0	27	1	31	2	28	2
112TCE	3	0	0	0	1	0	0	0
TCLEE	22	0	27	1	29	3	35	2
CLC6H5	9	1	3	1	21	3	30	2
CL	158	5	125	4	150	9	145	5
FL	100	4	75	3	142	7	132	5
SO4	158	5	126	4	160	9	145	5
NIT	24	0	26	2	65	7	34	2
CA	34	2	27	2	67	7	38	3
MG	34	2	28	2	67	7	38	3
NA	34	2	28	2	67	7	38	3
K	34	2	28	2	62	6	37	2
CDTOT	0	1	1	0	2	0	14	1
CRTOT	2	1	11	1	19	3	16	1
CUTOT	1	1	1	0	6	0	8	2
PBTOT	0	0	0	0	3	0	8	0
ZNTOT	21	1	12	1	40	2	26	3
HGTOT	0	1	0	0	0	0	1	0
ASTOT	16	2	32	3	55	4	52	3

Source: ESE, 1988

wells can be located by cross-referencing the distribution maps and the monitoring well location map presented in Figure B-24A.

Ground-water flow under unconfined conditions occurs primarily in saturated alluvium. Apparent water table conditions in bedrock beneath areas of unsaturated alluvium indicate that limited unconfined flow may occur through sandstones, siltstones, and weathered clayshales of the Denver Fm. Occurrence and lateral extent of unsaturated alluvium is based on the elevation of the bedrock surface relative to the local water table. Unsaturated alluvium is generally associated with topographically elevated areas of the bedrock surface. This potential unconfined flow within the uppermost weathered Denver Fm may permit transport of contaminants beneath unsaturated alluvial sediments, however, the rate of transport is likely to be relatively slow, as previously discussed. For this reason, contour lines may cross the dry alluvium, but are dashed in these areas.

Contoured maps are provided in Appendix B (Figures B-68A through B-82D) for analytes that were frequently detected in the study area. Contoured distribution maps were prepared for the following compounds or groups of compounds:

- DIMP;
- DBCP;
- DCPD;
- Combined organosulfurs;
- 1,4-Oxathiane;
- 1,4-Dithiane;
- Dieldrin;
- Endrin;
- Chloroform;
- Trichloroethene;
- Tetrachloroethene;
- 1,2-Dichloroethane;
- Arsenic;

- Fluoride; and
- Chloride.

For compounds that exhibit limited numbers of detections or widely dispersed detections and for which contouring is not appropriate, concentration point plots are provided. The following compounds are presented on point plots in Appendix B (Figures B-83A through B-99D), with concentrations posted for values exceeding the CRLs:

- Aldrin;
- Isodrin;
- p,p'-DDT;
- p,p'-DDE;
- 1,1-Dichloroethene;
- t-1,2-Dichloroethene;
- Methylene Chloride;
- Carbon Tetrachloride;
- 1,1-Dichloroethane;
- 1,1,1-Trichloroethane;
- 1,1,2-Trichloroethane;
- Benzene;
- Chlorobenzene;
- Toluene;
- Ethylbenzene;
- m-Xylene; and
- o- and/or p-Xylene.

5.1.2 CONTAMINANT CONCENTRATIONS AND DISTRIBUTIONS

A review of contaminant distribution maps from previous studies prepared by Thompson et al. (1985, RIC#86078R01), PMSO (1987a, RIC#87320R01 and 1987b, RIC#88054R01), and ESE (1987b, RIC#87253R01) indicate several general trends in contaminant migration. The contaminants appear to follow the alluvial flow

directions inferred from the water table maps presented in Figures B-25A through B-25D. The paleochannel features inferred from the bedrock surface map (Figure B-10) and illustrated in the saturated thickness map (Figure B-28) exercise a significant influence on the overall migration patterns. As illustrated on the alluvial aquifer transmissivity map (Figure B-29), the paleochannels contain the thickest extent of coarse grained, highly permeable sediment. This coarse grained sediment will be the preferred pathway for ground-water flow and contaminant transport.

There are five dominant pathways for contaminant transport, as well as five minor ones. These pathways are illustrated in Figure 5.1-1. The positions of the transport pathways are summarized below. The contoured distribution maps and the descriptions in the text delineate the preferred pathways for each contaminant.

Upgradient of the NBCS, a pattern of contaminant distribution extends from the vicinity of Basin F, trending north and northeast to east-central Section 23 and west-central Section 24, where the dominant direction of transport is then directly north to the NBCS. There are three transport pathways through which most of the contaminated ground water flows. Two of these pathways, separated by approximately 1/4 mile, connect the Basin F area to the NBCS and are labelled the Section 26 Northern and Northeastern Pathways in Figure 5.1-1. The third pathway upgradient of NBCS is a minor pathway transporting contaminants from the North Plants vicinity toward the Northeast Pathway and is labelled the North Plants Pathway. The distribution of the different contaminants varies significantly and is a result of different source areas, migration pathways, and chemical and physical properties.

Downgradient of the NBCS, contaminants have been observed along two primary alluvial pathways and two minor pathways. These pathways follow flow directions that are discernable from the water table maps (Figures B-25A through B-25D). The first of the primary pathways corresponds to an inferred paleochannel feature in the bedrock surface located in the vicinity of the present day First Creek. This flow direction is labelled the First Creek Pathway. The primary direction of flow along

this pathway is to the northwest. The second primary direction of ground-water and contaminant flow is to the north, from the boundary east of Peoria Street, through the central portion of Section 13. This pathway is labelled the Northern Pathway. The First Creek and the Northern flow paths are separated by an area of unsaturated alluvium, present in the northeast quadrant of Section 14, and northwest quadrant of Section 13. There are two minor pathways downgradient of the NBCS. The East 96th Ave Pathway is located in south-central Section 13 and trends north. The West 96th Ave Pathway is located in central Section 14 and trends northwest.

Various contaminants have been detected in the offpost area under previous studies as well as under the Task 25 study. In the First Creek Pathway DIMP, DCPD, CPMSO₂, 1,4-dithiane, and 1,2-dichloroethane are the most widely detected organic contaminants. The highest concentrations of these contaminants offpost occur more than 1/4 mile north of the RMA boundary. In the Northern Pathway DBCP, chloroform, DIMP, tetrachlorethene, and CPMSO are the most widely detected organic contaminants. The highest offpost concentrations of these contaminants occur 1/2 mile north of the RMA boundary. The historical distribution for many of these contaminants appears to be similar to that detected under the Task 25 program, although some of the contaminants were not analyzed for on a regular basis previously. Concentrations within a quarter mile north of the NBCS, however, generally appear to be declining with time. These declining concentrations are probably due to the operational effects of the NBCS. How long it might take to leach residual contamination from offpost sediments is difficult to predict. Contaminant transport is dependent upon the characteristics of each contaminant, characteristics of the soils, and the volume of water flowing through the aquifer. It is expected that concentrations of relatively more mobile compounds, such as DIMP, will decline more rapidly than concentrations of less mobile compounds, such as dieldrin.

In the vicinity of the NWBCS there is one major transport pathway and two minor ones. The primary transport pathway follows a dominant northwest trend from the

pattern follows the alluvial flow directions northwest through Section 27 and is labelled the Section 26 Western Pathway. In central Section 27, the flow of ground water and contaminants trends north through a zone of relatively high transmissivity (Figure B-29) to the NWBCS. This pattern was observed prior to installation of the NWBCS, but the pumping wells along the boundary may accelerate transport in this area. There is also a minor distribution pattern which trends northwest through Section 22, from Section 26 to the NWBCS. This pathway is labelled the Section 26 Northwestern Pathway. The third pathway is a minor one labelled the Southern Basins Pathway and trends west-northwest through the south-central portion of Section 27.

A summary discussion of the concentrations and distributions of each target analyte or group of analytes detected in the study area is presented below. The analyte distributions observed in Task 25 were compared with available data generated in previous investigations and any variations were noted. These investigations include the more recent, localized (Thompson *et al.*, 1985, RIC#86078R01; PMSO, 1987a, RIC#87320R01 and 1987b, RIC# 88054R01) and regional (ESE, 1987b, RIC#87253R01) studies previously mentioned. The sampling protocol used in these monitoring programs is the same as that used for the Task 25, FY87 program. Comparisons are somewhat limited due to the variation in sampling networks, the variation in CRLs, and the fact that previous maps of contaminant concentration have been contoured based solely on concentration values and have not integrated hydrogeologic factors as has been done in analysis of the FY87 data.

Historical data generated prior to the above-mentioned studies includes that presented in a report by Spaine *et al.* (1984, RIC#85133R04). Analyte distribution maps of onpost RMA, referred to as Spaine maps, were constructed based on water quality sampling conducted between 1980 and 1983. The analyte detections were primarily from ground water samples from alluvial monitoring wells. However, where the alluvium was unsaturated, detections in ground water from the Denver Fm were utilized. Due to the combining of alluvial and Denver detections on the same map

and the variation in sampling collection and analysis techniques, comparisons with Task 25 data were made on a regional, qualitative basis. Water quality data generated from 1975 through 1984 and contained in the USATHAMA data base was used to construct historical chemical distribution maps of the onpost RMA area (ESE, 1987b, RIC#87253R01). The maximum analyte concentration observed over the 10-year period was plotted, and the analyte detections in the alluvial and Denver Fm were outlined. Since this compilation of data has not undergone rigorous quality control and quality assurance, and since it presents sampling over a long period of time with various sampling and analysis techniques, comparisons with Task 25 analyte distributions were made on a regional, qualitative basis. Historical data was also included in onpost RMA maps compiled by MKE (unpublished data, 1986). Water quality data generated up to 1986 was used to delineate generalized contaminant distributions and the relation to source areas. Comparisons of the FY87 contaminant distribution maps with maps constructed previously based on historical data are limited due to a variation in sampling networks and CRLs and due to the fact that historical maps did not incorporate hydrogeologic factors.

5.1.2.1 DIMP

Observed concentrations of DIMP in the study area ranged from the 1986-87 CRL of 10.5 micrograms per liter (ug/l) to 5,180 ug/l. The distribution maps are presented in Figures B-68A through B-68D. The isoconcentration line representing the CRL was rounded from 10.5 to 11 ug/l and all detectable values between are included within this contour interval. Other isoconcentration lines represented on the maps include 50, 100, 500, and 1,000 ug/l. In addition, there is a 5,000 ug/l contour line on the second quarter map.

Upgradient of the NBCS the distribution of DIMP is characterized by a laterally extensive plume that covers all of the saturated areas of Section 23 and up to 50 percent of Section 24. The DIMP distribution is over 8,000-ft wide as it enters the study area, decreasing to less than 3,500-ft wide in the central portions of Sections 23

and 24, and then increasing to approximately 4,500-ft wide just upgradient of the NBCS.

The predominant DIMP pathway enters the study area along the southern boundary of Section 23, trending north-northwest toward the NBCS. The zone of highest DIMP concentrations occurs along the Section 26 Northern Pathway, and includes Wells 23102, 23057, 23052, 23004, 23160, and 23119. During the last three sampling quarters this zone extended to the west to include Wells 23142, 23050, and 23033. This caused a compression of the contour lines on the western side of the distribution. Samples from Well 23057 exhibited the highest mean concentration of DIMP for wells sampled all four quarters, 3,540 ug/l. Concentrations in these samples ranged from 3,020 to 4,740 ug/l.

There is also a pathway for DIMP transport which enters the study area along the southern boundary of Section 24 and trends northwest to join the main DIMP distribution. This corresponds to the previously described North Plants Pathway and includes Wells 24081, 24111, 24092, and 24027.

Downgradient of the NBCS, DIMP is widely distributed in the western half of Section 13 and in Section 14 southeast of the canals. During the first two quarterly sampling events the predominant direction of DIMP transport appeared to be to the northwest along the First Creek Pathway. The third and fourth quarter sampling of newly installed wells in Section 13 identified a component of DIMP transport along the Northern Pathway. The well with the highest mean concentrations of DIMP in the offpost area for FY87 was 37313. The average concentration for samples from this well was 3,920 ug/l, with a range of values from 2,170 to 5,180 ug/l. Samples from Well 37391 exhibited concentrations of greater than 2,000 ug/l, the highest concentrations in the Northern Pathway. The third and fourth quarter sampling of newly installed piezometers, located just downgradient of the soil-bentonite barrier, indicated concentrations of DIMP in this area as high as 1,000 ug/l. Concentrations

an order-of-magnitude lower directly downgradient may indicate that contaminants are being retained against the soil-bentonite barrier within stagnant water.

DIMP is a relatively mobile compound in ground-water, compared to a relatively immobile compound such as dieldrin. However, the leaching characteristics of a contaminant from soil are not only dependent upon the mobility of the contaminant but also upon characteristics of the soil, such as organic carbon content, as well as the volume of water flowing through the aquifer materials. Concentrations of DIMP in offpost wells sampled have generally been decreasing over the last 10 years, since the installation of the NBCS pilot system. It is likely that the majority of the DIMP contamination presently detected offpost is the result of historical contamination which occurred prior to the installation of the NBCS. This contamination is being leached from the sediments and the highest concentrations are presently detected more than 1/4 mile north of the RMA boundary.

The DIMP distribution exhibits a component of transport from the western portion of the NBCS toward the canals, along the West 96th Ave Pathway. Chloride and fluoride are the only other analytes that appear to exhibit a similar pattern of occurrence. Concentrations of DIMP in this area are generally less than 500 ug/l, but may be higher.

Upgradient of the NWBCS, the DIMP plume enters the study area along the eastern boundary of Section 27 and is transported along the Section 26 Western Pathway. Concentrations are relatively low in this area, generally less than 50 ug/l. The fourth quarter distribution map indicates a component of transport northwest through the southeastern quarter of Section 22, along the Section 26 Northwestern Pathway. This area of occurrence is based on a fourth quarter sample from Well 22049, but this well was not sampled in the previous quarters. Well 22008 was the upgradient NWBCS well sampled all four quarters with the highest mean concentration, 42.1 ug/l. Concentrations of DIMP in these samples ranged from 25.5 to 58.3 ug/l.

Downgradient of the NWBCS, DIMP distribution was limited to samples from Wells 22015, 22016, and 22059, located directly downgradient of the soil-bentonite barrier. Concentrations in this area were generally less than 20 ug/l.

A review of DIMP distribution maps from the previous NBCS and NWBCS reports (PMSO, 1987a, RIC#87320R01 and 1987b, RIC#88054R01) indicates similar trends during FY87 despite variations in the monitoring network. The previous reports did not employ a CRL isoconcentration line, which may account for small variations observed on the maps. The historical DIMP distribution map (ESE, 1987b, RIC#87253R01) and the Spaine map (Spaine *et al.*, 1984, RIC#85133R04), display similar trends to the FY87 maps.

5.1.2.2 DBCP

Observed concentrations of DBCP in the study area during FY87 ranged from the CRL of 0.130 ug/l to 8.84 ug/l. Distribution maps are presented in Figures B-69A through B-69D. Isoconcentration lines employed on the maps include the CRL and 0.2, 1, 2, and 5 ug/l. The maps indicate very little apparent variation in concentration and distribution of DBCP from quarter to quarter.

Samples collected from wells located upgradient of the NBCS exhibit a distribution of DBCP that enters the study area in southeastern Section 23 and trends north-northwest toward the NBCS. The distribution is approximately 2,000-ft wide as it enters the study area, decreasing to 1,000-ft wide in the northwestern quarter of Section 24 and then spreading laterally to a width of approximately 2,500 ft as it reaches the NBCS.

The samples exhibiting the highest concentrations of the contaminant were collected from wells located on the axis of the distribution, along the Section 26 Northeastern Pathway. This axis is oriented primarily along the western edge of Section 24 and the southwestern edge of Section 23 and includes Wells 23096, 24049, and 24178. It is located approximately 1/4 mile to the east of the distribution axes for contaminants

such as DIMP, chloride, and trichloroethene. Of the NBCS upgradient wells sampled all four quarters, the well with the highest concentration of DBCP was 24049. The mean for the four samples was 6.73 ug/l, with a range of values of 5.38 to 8.50 ug/l.

In the vicinity of First Creek, upgradient of the NBCS, there were sporadic detections of DBCP during FY87. This trend includes detections in samples from Wells 24182, 24115, and 24117. Of these wells, only the samples from Well 24182 exhibited detections in all four sampling quarters.

During the first two sampling quarters, the distribution of DBCP downgradient of the NBCS appeared to be limited to the First Creek Pathway in Section 13. Detectable concentrations ranged from 0.173 to 0.87 ug/l. The third and fourth quarter sampling of newly installed wells in Section 13 indicated a predominant direction of transport for DBCP in the Northern Pathway along the western edge of Section 13. The DBCP concentrations in the third and fourth quarter samples from Well 37391 were the highest observed in the Task 25 offpost area during FY87, 4.37 to 4.68 ug/l.

Historically DBCP has been analyzed for in samples from offpost wells. Wells which have been analyzed for trends over time, including 37308, 37309, and 37313, indicate no overall trends with time. Concentrations have been generally decreased in 37308, increased in 37309, and remained relatively static in 37313.

The DBCP plume enters the NWBCS upgradient study area along the eastern boundary of Section 27. Transport occurs along the Section 26 Western Pathway to the west-northwest, shifting directly north in north-central Section 27. Concentrations of DBCP detected in this area ranged from the CRL to 0.440 ug/l. Samples collected from Well 22008 exhibited the highest mean concentration for wells sampled all four quarters in the NWBCS upgradient area. The mean value for these samples was 0.338 ug/l, with a range of values from 0.282 to 0.367 ug/l.

Downgradient of the NWBCS the detections of DBCP were limited to samples from Wells 22015 and 22059. Well 22015 was sampled all four quarters. These samples exhibited a range of values from less than the CRL to 0.269 ug/l. These detected concentrations in samples from wells located immediately downgradient of the barrier may indicate stagnant water trapped against the barrier.

A comparison of DBCP distribution maps from the previous two years and the maps from FY87 indicates similar concentrations and distribution for the contaminant for the different programs (PMSO, 1987a, RIC#87320R01 and 1987b, RIC#88054R01). The monitoring network varied under the different programs, which may cause the contaminant distribution to appear slightly different from quarter to quarter. Very few variations are evident between the Task 25 DBCP distribution maps and the distribution maps based on historical data generated prior to and including 1984 (Spaine *et al.*, 1984, RIC#85133R04; MKE unpublished data, 1986; ESE, 1987b, RIC#87253R01). On the Spaine map, the DBCP distribution extends beyond the NWBCS into the southwestern portion of Section 22. This may be explained by the fact that the NWBCS was not operational at the time the data for this map was obtained. The historical DBCP distribution map (ESE, 1987b, RIC#87253R01) indicates isolated DBCP detections in the south central portion of Section 24. These detections are not indicated on the other DBCP distribution maps examined.

5.1.2.3 DCPD

Observed concentrations of DCPD in the study area during FY87 ranged from the CRL of 9.31 ug/l to 1,420 ug/l. Distribution maps for DCPD are presented in Figures B-70A through B-70D. Isoconcentration lines illustrated on the maps include the CRL and 50, 100, 500, and 1,000 ug/l.

Upgradient of the NBCS, the DCPD plume enters the study area along the south-central boundary of Section 23. The distribution in this area is less than 2,500-ft wide and it trends northeast to the 23/24 section line. Near the eastern boundary of

Section 23 the distribution of contaminant decreases to approximately 1,200-ft wide and the direction of transport shifts north toward the NBCS.

There is minimal lateral spread of the contaminant just upgradient of the soil-bentonite barrier. Samples with the highest concentrations of DCPD were collected from wells located on the axis of the distribution, along the Section 26 Northern Pathway. Wells 23049, 23095, 23179, 23004, 23052, 23123, and 23160 are included in this trend. Samples from Well 23049 contained the highest mean concentrations in the study area, 1,280 ug/l. Concentrations of these samples ranged from 1,100 ug/l to 1,420 ug/l.

The predominant direction of transport offpost appears to be to the northwest along the First Creek Pathway in Sections 13 and 14. Concentrations ranged from the CRL to 736 ug/l. Samples from Well 37309 exhibited the highest mean concentrations of DCPD in the offpost area, 589 ug/l. Concentrations in these samples ranged from 475 to 736 ug/l. Concentrations of DCPD in offpost wells in the vicinity of 37308 and 37309 appear to have decreased somewhat since FY85. Concentrations in this area are very similar to those detected in FY86. The fourth quarter sampling of newly installed piezometers, just downgradient of the NBCS, indicated two wells in this area with sampled concentrations of DCPD of less than 200 ug/l. The diminished flow against the soil-bentonite barrier and subsequent ground-water stagnation may be responsible for the retention of the contaminant against the barrier.

Samples from the vicinity of the NWBCS were analyzed for DCPD for each quarter of FY87. DCPD was not detected in samples from any of these wells.

A comparison of DCPD distribution maps from FY87 and the two previous sampling programs (PMSO, 1987a, RIC#87320R01 and 1987b, RIC#88054R01) indicates similar trends for both the onpost and offpost study areas. Maps based on data obtained prior to these sampling programs (Spaine et al., 1984 RIC#85133R04; MKE unpublished data, 1986; ESE, 1987b, RIC#87253R01) exhibit similar trends to the

FY87 data. Unlike the DCPD distribution maps from FY87, DCPD detections close to the CRL are indicated on the MKE maps near the NWBCS, and DCPD detections are outlined in this area on the historical distribution map. The reason for this may be that the NWBCS was not operational at the time these samples were collected.

5.1.2.4 Combined Organosulfur Compounds

The combined organosulfur compounds (COS) include p-chlorophenylmethyl sulfide (CPMS), p-chlorophenylmethyl sulfoxide (CPMSO), and p-chlorophenylmethyl sulfone (CPMSO₂). The concentrations of these three compounds have been added together to generate combined concentration distribution maps for the four quarters of FY87. The maps are presented in Figures B-75A through B-75D. Each of these organosulfur compounds has a slightly different CRL, ranging from 1.10 ug/l for CPMS to 4.70 ug/l for CPMSO₂. The highest CRL for the three compounds was used as the lowest isoconcentration line on the maps. Table 5.1-2 provides a list of samples exhibiting detectable concentrations of CPMS, CPMSO, or CPMSO₂ that were between the lowest and the highest CRL during each of the four sampling quarters. Contour lines used to illustrate the concentration distribution include the CRL and 10, 20, 50, 100, and 500 ug/l.

Concentrations of the COS compounds detected in the study area ranged from the CRL to more than 1,000 ug/l. There is a broad distribution of COS compounds, from approximately 3,200- to 5,000-ft wide, in Section 23, which enter the study area along the southern boundary of the section. The zone of highest concentrations, within the distribution, follows the Section 26 Northern Pathway. This pathway trends northeast to the 23/24 section line, where it shifts orientation due north to the NBCS. The distribution broadens against the upgradient side of the soil-bentonite barrier, spreading into the northwest quarter of Section 24. The distribution exhibits closely spaced isopleths near its boundaries, which is a result of generally uniform concentrations and indicates a limited zone of diffusion and/or dispersion. The highest concentrations of COS compounds were detected in samples from Wells

Table 5.1-2. Combined Organosulfur Detections Below 4.7 ug/l

QUARTER	SITE ID	CONCENTRATION (ug/l)
Fall 1986	22008	3.530
	22031	3.320
	23047	4.690
	23048	3.780
	23150	4.250
	23151	4.520
	23211	4.150
	24150	3.680
	24184	4.330
	24185	3.920
	24187	4.610
	24188	4.290
	27006	4.100
	27007	3.340
	27011	4.140
	27031	4.140
	27045	3.670
	27062	3.930
	27063	4.230
	27082	3.520
Winter 1987	23047	3.500
	24106	4.480
	24181	3.980
	24183	2.980
	24187	3.050
	24188	4.010
Spring 1987	02025	3.160
	02034	3.890
	02035	4.090
	23047	3.770
	23205	2.750
	24003	2.830
	24106	3.900
	24181	3.670
	24183	3.690
	24187	4.410
	24188	3.360
	26066	2.500
	34002	3.790
	35066	3.640
	36110	3.650
	36139	3.790
	37368	3.430
	37377	3.070
	37381	3.640
Summer 1987	23047	3.580
	24106	4.610
	24181	3.520
	24183	3.640
	37368	3.400
	37377	2.540

Source: ESE, 1988

23052, 23095, 23179, and 23049. The highest concentrations were detected in samples from Well 23179. This well was not sampled during the second and fourth quarters, but the concentrations detected for the first and third quarters were 901 ug/l and 1,080 ug/l, respectively.

There is a zone upgradient of the NBCS in the northeast quarter of Section 23, which exhibits relatively low concentrations of COS compounds. This area correlates very well with a zone of lower transmissivity illustrated in Figure B-29. The predominant pathway for transport of these compounds is apparently deflected around this area of low flow.

Upgradient of the NBCS in the First Creek channel there were numerous low concentration detections of COS compounds during FY87. These include detections in samples from Wells 24106, 24187, 24188, 24182, and 24183. The relatively low concentrations in these samples, less than 20 ug/l, indicate this is not a major pathway for the COS compounds reaching the NBCS.

Downgradient of the NBCS, there is a distribution of COS compounds trending northwest along the First Creek Pathway. This occurrence did not give any indication of reaching the vicinity of the O'Brian Canal and Burlington Ditch during FY87. Wells with samples exhibiting the highest concentrations in this pathway include 24161, 37308, and 37309. Concentrations in Well 37309 range from 44.4 to 94.8 ug/l. Concentration ranges are similar in Wells 37308 and 24161. The fourth quarter sampling of newly installed piezometers, located just downgradient of the soil-bentonite barrier, indicates downgradient concentrations of COS compounds in excess of 100 ug/l. Although flow immediately adjacent to the downgradient side of the barrier is probably limited and the water fairly stagnant, the potential exists for transport of COS compounds from this area directly offpost.

Historical data for the COS compounds are limited. Concentrations of the COS compounds in samples from offpost wells that have been sampled previously (37308

and 37309) indicate similar concentrations from FY84 to FY87. There are no apparent increases or decreases in concentrations over this time period. The detections of COS compounds in samples from wells 37308 and 37309 may represent residual historical contamination which occurred prior to the operation of the NBCS.

The sampling of newly installed wells in the third and fourth quarters indicates that there is a component of transport for the COS compounds in the Northern Pathway in Section 13. This pathway is bracketed by detections in Wells 37389, 37391, and 37367. Samples from Well 37391 contained the highest detectable concentrations of COS compounds for this pathway, including a concentration of 157 ug/l during the third quarter and 143 ug/l during the fourth quarter.

Upgradient of the NWBCS there were few detections of COS compounds. Isolated low concentration detections were observed in first quarter samples from Wells 27024, 27027, and 27040 in east-central Section 27, as well as in first quarter samples from Wells 27075, 27077, and 27078 in north-central Section 27. There were also isolated detections in first quarter samples from Wells 27004 and 22053. There were no observed offpost detections downgradient of the NWBCS. Analyses for COS compounds in the vicinity of NWBCS were not conducted under Task 25 for the subsequent quarters. Third quarter sampling of regional program wells (Task 44) in the Task 25 area indicated low concentration detections of COS compounds in samples from Wells 27040 and 27062.

Comparison of the Task 25 results to the previous studies (Thompson *et al.*, 1985, RIC#86078R01; PMSO, 1987a, RIC#87320R01 and 1987b, RIC#88054R01) indicates a similar pattern of contamination upgradient of the NBCS over FYs 1985, 1986, and 1987. Variations are attributable to differences in the monitoring network, as well as a reduction in the highest CRL for FY87 from 20 ug/l to 4.7 ug/l. The distribution of COS compounds was not assessed in the vicinity of the NWBCS during the previous studies.

Distributions of COS compounds derived from data generated prior to the above-mentioned studies (Spaine *et al.*, 1984, RIC#85133R04; MKE unpublished data, 1986; ESE, 1987b, RIC#87253R01) resembles the COS compound distributions from FY87. Differences can be attributed to the monitoring network and to analysis of CPMSO₂ only (MKE unpublished data, 1986; ESE, 1987b, RIC#87253R01) rather than all three COS compounds. In the vicinity of the NWBCS, CPMSO₂ was detected from 1977 to 1980 in east-central Section 28 (MKE unpublished data, 1986).

5.1.2.5 1,4-Oxathiane

Concentrations of oxathiane detected in samples collected during FY87 ranged from the CRL of 2.0 ug/l to 25 ug/l. The contoured distribution maps for oxathiane are presented in Figures B-73A through B-73D. Isoconcentration lines on the maps include the CRL and 5, 10, and 20 ug/l. The general areas of distribution remained fairly consistent during FY87.

The axis of the oxathiane plume upgradient of the NBCS trends northeast from the Basin F area toward the 23/24 section line where it shifts orientation due north toward the boundary. The axis of the distribution is the zone of highest oxathiane concentrations. Wells 23052, 23179, and 23102 are all located on the axis of the distribution which trends along the Section 26 Northern Pathway. Samples from Well 23052 generally exhibited the highest concentrations in the study area, ranging from 19.1 to 25.1 ug/l, over the four quarters.

The distribution varies from a minimum of 1,200-ft wide, upgradient of the soil-bentonite barrier during the fourth quarter sampling, to a maximum of 4,200-ft wide. The isoconcentration lines are more closely spaced on the eastern side of the distribution, indicating a more extensive zone of dispersion to the west. There is an area of relatively low concentrations against the upgradient side of the soil-bentonite barrier, in the northeast quarter of Section 23. Concentrations are generally close to the detection limit in this area of relatively low transmissivity (Figure B-29).

Downgradient of the NWBCS the oxathiane distribution is characterized by isolated detections. Samples from Well 37313 generally exhibit detectable oxathiane, but at concentrations below 5 ug/l. The fourth quarter sampling of the newly installed piezometers, just downgradient of the soil-bentonite barrier, indicated only one isolated detection of oxathiane between the barrier and the RMA boundary. This detection was in a sample from Well 23217. Data for 1979 presented by MKE (unpublished data, 1986) indicate concentrations of oxathiane in the vicinity of what is now the NWBCS of greater than 5 but less than 20 ug/l.

There were no detections of oxathiane in the immediate vicinity of the NWBCS during the first quarter sampling. There was one isolated detection in a first quarter sample from Well 27024, located in the east-central portion of the section. Analysis for oxathiane in samples from wells located in the vicinity of the NWBCS was limited in the subsequent quarters. The only other detection during FY87 was in a sample from Well 27040, located in east-central Section 27.

The distribution of oxathiane in the study area was not assessed during the localized FY85 and FY86 studies. In the regional study conducted during FY86 (ESE, 1987b, RIC#87253R01) and in earlier investigations (Spaine *et al.*, 1984, RIC#85133R04; MKE unpublished data, 1987), the oxathiane distributions are similar to that of FY87. Small variations are probably a result of differences in the monitoring networks.

5.1.2.6 1,4-Dithiane

Concentrations of dithiane detected in the study area during FY87 range from the CRL of 3.34 ug/l to over 200 ug/l. The distribution maps for dithiane are presented in Figures B-74A through B-74D. Isoconcentration lines of the CRL and 5, 10, 20, and 50 ug/l are illustrated on each map. An additional isoconcentration line of 100 ug/l is shown on the first quarter map. The general areas of distribution remained fairly consistent over the four quarters of FY87. There were, however, fluctuations in the maximum concentration levels within the distribution.

Upgradient of the NBCS, the axis of the distribution trends northeast from the Basin F area to the 23/24 section line where it changes orientation to the north toward the containment/treatment system. Wells 23049, 23179, 23095, 23057, 23102, 23052, 23004, and 23160 are located on the axis of the distribution, which follows the Section 26 Northern Pathway. Samples from all of these wells exhibit relatively high concentrations of dithiane, with Well 23052 exhibiting the highest mean concentration for the four quarters, 112 ug/l. Concentrations in samples from Well 23052 ranged from 74.3 to 208 ug/l over the four quarters. The concentrations in some wells decreased by up to an order of magnitude between the first and the second quarters. However, during the subsequent quarters values were consistent with the second quarter.

Dithiane is characterized by a distribution very similar to that for oxathiane and COS. The isoconcentration lines on the eastern side of the distribution are spaced more closely than those on the west, indicating a greater degree of dispersion to the west. An area of low concentrations, similar to that characterized by oxathiane, is present just upgradient of the soil-bentonite barrier in northeast Section 23. As presented previously, this area correlates well with a low transmissivity zone illustrated in Figure B-29.

The distribution of dithiane downgradient of the NBCS appears to be indicative of transport exclusively along the First Creek Pathway, in a pattern that is consistent from quarter to quarter. Concentrations in this area range from the CRL to 19.3 ug/l. These values are very similar to those presented on the MKE (unpublished data, 1986) map. This map indicates values of 5 to 20 ug/l in 1979 directly downgradient of the area that is now the NBCS. The highest concentration during the four quarters of FY87 was detected in a sample from Well 37313. There were consistent low concentration detections in samples from Well 24161. These were the only dithiane detections in samples collected from wells located between the soil-bentonite barrier and the RMA boundary during the first three quarters of sampling.

These values are not contoured on the maps because they are below the value of the CRL isoconcentration line. The fourth quarter sampling of the newly installed downgradient piezometers, located adjacent to the soil-bentonite barrier, indicated one detection of dithiane in a sample from Well 23217.

There were no detections of dithiane in the vicinity of the NWBCS during the first quarter sampling period for FY87. Dithiane analyses were performed on a very limited basis during subsequent quarters. The few samples collected in the vicinity of NWBCS during second, third, and fourth quarters of FY87 verified the absence of dithiane in this area.

The distribution of dithiane was not assessed during the FY85 and FY86 studies conducted near the containment systems (Thompson *et al.*, 1985, RIC#86078R01; PMSO, 1987a, RIC#87320R01 and 1987b, RIC#88054R01). Dithiane distribution maps constructed as a result of the FY86 regional study (ESE, 1987b, RIC#87253R01) and earlier investigations (Spaine *et al.*, 1984, RIC#85133R04; MKE unpublished maps, 1986) resemble the FY87 maps. The FY87 maps do indicate higher dithiane concentrations in the northeast quarter of Section 23 than is indicated on earlier maps. This may be due to fewer sampling points in this area on earlier maps.

5.1.2.7 Chlorinated Pesticides

Several chlorinated pesticides were detected at concentrations exceeding CRL's in samples from the alluvial aquifer. Dieldrin and endrin were the most frequently detected chlorinated pesticides. These two compounds are stereoisomers produced by the oxidation of the chlorinated pesticide aldrin. They are relatively stable breakdown products of aldrin, and their persistence in the environment is greater than that of aldrin, hence their distribution is widespread. Aldrin, isodrin, p,p'-DDT, and p,p'-DDE were detected in a limited number of samples collected during the Task 25 study. Chlordane, the remaining target chlorinated pesticide, was not detected in concentrations exceeding CRLs in any alluvial aquifer samples collected.

Hexachlorocyclopentadiene (HCCPD), an intermediate in the synthesis of stable chlorinated cyclodiene insecticides, such as aldrin, endrin, and dieldrin, was not detected in any study area samples at concentrations exceeding CRLs.

Dieldrin

Concentrations of dieldrin detected in study area samples ranged from the CRL of 0.060 ug/l to over 4.27 ug/l. Contoured distribution maps are presented in Figures B-71A through B-71D. Isoconcentration lines of the CRL and 0.2, 0.5, 1, and 2 ug/l are illustrated on each map. The general area of contaminant distribution is similar for each quarter of FY87, but there are fluctuations in maximum concentrations detected over the four quarters.

Concentrations in the north boundary area ranged from the CRL to greater than 4.27 ug/l. This higher concentration was detected in a sample from Well 23004, collected during the first quarter of FY87. Samples from this well generally exhibited the highest concentrations of dieldrin in the study area, ranging from 2.60 to 4.27 ug/l. The area of highest concentration within the dieldrin distribution trends from the southern portion of Section 23 north and northeast to the NBCS in Sections 23 and 24. This trend corresponds to both the Section 26 Northeastern and Section 26 Northern Pathways. Dieldrin appears to have some component of transport within each of these pathways. Concentrations of dieldrin decrease in samples collected to the east and west of this central trend. The alluvial contaminant distribution in the central portion of Sections 23 and 24 is approximately 3,500-ft wide, broadening to more than 5,500-ft wide at the NBCS. There is an area of relatively low concentration against the western end of the NBCS which varies in extent but occurs consistently from quarter to quarter. The dimensions of the dieldrin plume appear to be fairly consistent from quarter to quarter, although the maximum concentrations of samples within the observed distribution do fluctuate over the four sampling quarters. In particular, the concentration in the sample from Well 23095 varies from less than the CRL to 2.75 ug/l. There is a general decrease in concentration for samples collected from wells just upgradient of the NBCS in Sections 23 and 24, over the

period of the Task 25 investigation. These decreases in concentration cause the 2 ug/l isopleth to shift south of the boundary after the first quarter of FY87. Continued sampling will determine if this is a progressive temporal trend or merely a cyclical seasonal fluctuation. These fluctuations alter the configuration of the dieldrin isoconcentration lines, but not the overall extent of distribution.

Offpost and downgradient of the NBCS in Sections 13 and 14, dieldrin appears to follow three distinct trends. There is a northwest trending distribution of dieldrin along the First Creek Pathway. This pathway is most notably present in the first quarter, and appears to diminish in extent during subsequent quarters. An examination of the maps from the previous two years of sampling indicates that dieldrin does not always appear to be present in the offpost First Creek Pathway (PMSO, 1987a, RIC#87320R01). Dieldrin also appears to follow a trend north along the western boundary of Section 13. This trend has become more apparent in the last two quarters as the density of available well sampling locations increased. There is also a dieldrin distribution that trends north through the central portion of Section 13 to Well 37320 at the northern boundary of the section. This distribution corresponds to the East 96th Avenue Pathway. The concentrations in this pathway are relatively low, but they are consistent from quarter to quarter. The samples from Well 37312, located directly downgradient of the NBCS and east of Peoria St, exhibited relatively high concentrations of dieldrin over the four sampling quarters. The concentrations of dieldrin in samples from this well ranged from 0.135 to 1.62 ug/l, indicating some fluctuation in concentrations. The fourth quarter sampling of newly installed piezometers, downgradient of the NBCS, indicate concentrations in this area as high as 3.47 ug/l. These relatively high concentrations may be caused by stagnant contaminated water pooling against the barrier.

The distribution of dieldrin upgradient of the NWBCS trends north and northwest from Section 27 into Section 22. The maps (Figures B-71A through B-71D) indicate an area of relatively higher concentration trending from the southeast quarter of Section 27, north and northwest toward the NWBCS. The deflection of the high

concentration plume to the north is probably a result of the presence of a zone of increased transmissivity in this area, as well as pumping of the withdrawal wells at the NWBCS. The concentrations of dieldrin in the vicinity of the NWBCS range from less than the CRL to greater than 3.54 ug/l. The highest concentrations were detected in samples from Well 27030, which is located in the southeast quarter of Section 27. The sample from this well was not analyzed for dieldrin during the second quarter of FY87, but values for the other three quarters ranged from greater than 1.74 ug/l to 3.54 ug/l. Samples from wells located downgradient of the hydraulic barrier at the NWBCS did not generally exhibit concentrations of dieldrin. Downgradient of the soil-bentonite barrier, samples from Wells 37332 and 37333 exhibited low concentrations of dieldrin. In the offpost area southwest of the NWBCS, Wells 37334 and 37335 generally exhibited detectable concentrations of dieldrin.

The maps for FY87, when compared to the maps from the previous two years, indicate similar distribution and concentration trends. The distribution of dieldrin in Sections 23 and 24 appears more extensive in FY87 than in the previous two years. These variations probably result from differences in the monitoring networks for the two studies. Comparing the FY87 maps to maps based on pre-1985 data (Spaine *et al.*, 1984, RIC#85133R04; MKE unpublished data, 1986), similar trends of dieldrin concentrations are also indicated. Dieldrin detections are indicated in the southeast quarter of the Section 27 on historical maps; however, a continuation of high dieldrin concentrations to the north and northwest toward the NWBCS is not delineated. This may be due to variations in the sampling networks or CRLs or to the absence of pumping wells at the NWBCS during the historical sampling periods.

Endrin

The concentrations of endrin in the study area for FY87 ranged from less than the CRL of 0.060 ug/l to 3.43 ug/l. Contoured distribution maps for endrin are presented in Figures B-72A through B-72D. The isoconcentration lines used to contour the distribution for the four quarters are the CRL and 0.2, 0.5, 1, and 2 ug/l.

The distribution of samples with relatively high endrin concentrations is located along the border of Sections 23 and 24. This trend, with samples exhibiting concentrations in the 1 to 2 ug/l range, is oriented from the southeast quarter of Section 23 to the north-northeast. The axis is in a similar location to that of dieldrin, but the dieldrin distribution has greater lateral extent. During the first two quarters, the endrin distribution appears to be relatively narrow, less than 1,500-ft wide in the central portion of Sections 23 and 24, but in the last two quarters of FY87 the distribution exhibits a greater lateral spread. This is due to more detections of endrin to the west in the later quarters. During all four quarters, the centerline of high concentrations is stationary, as represented by samples from Wells 23096, 24049, 24008, 24101, and 24179. The well with the highest average concentration is 24179, located just upgradient of the soil-bentonite barrier at the NBCS. Concentrations in samples from this well ranged from 1.26 to 1.60 ug/l.

Downgradient of the NBCS, within Sections 13 and 14, the distribution of endrin is not well defined from quarter to quarter. Immediately offpost in the southwest quarter of Section 13, endrin was consistently detected each quarter. During the first quarter, this distribution appears to extend along the First Creek Pathway as far as the O'Brian Canal. For the subsequent quarters this distribution does not appear to extend more than 1/4 mile offpost, with the exception of an isolated detection in a sample from Well 37392 in the third quarter. In the fourth quarter, samples from wells installed immediately downgradient of the soil-bentonite barrier exhibited the highest concentrations in the study area, as high as 3.34 ug/l. These relatively high concentrations are probably due to stagnation of ground water against the barrier.

The endrin distribution in Sections 22 and 27, upgradient of the NWBCS, is characterized by isolated detections of relatively low concentration. Well 27028 was the only well sampled in the vicinity of the NWBCS that exhibited detectable concentrations of endrin during all four quarters.

The distribution of endrin during FY87 is similar to the distribution detected during the previous two years. The distribution maps in the vicinity of the NBCS for samples collected during FY85 and FY86 generally indicate a more variable and sporadic distribution in Sections 23 and 24 (PMSO, 1987a, RIC#87320R01). These apparent variations are due primarily to the differences in the sampling network between the two programs. Onpost the highest concentration of endrin during the previous two years, 15 ppb, was detected in the first quarter of FY86 in the east central part of Section 23. This location is west of the highest endrin concentration detected during the FY87 sampling. Offpost during FY85 and FY86, a few endrin detections were located approximately along the First Creek Pathway. This distribution is similar to that of the first quarter FY87, however the endrin concentrations are lower for FY87.

Endrin distribution maps from FY84 (Thompson *et al*, 1985, RIC#86078R01) exhibit a more northeast trend in the southeast quarter of Section 23 than maps from FY87. Endrin distributions indicated by earlier data (Spaine *et al*, 1984, RIC#85133R04; MKE unpublished data, 1986) also exhibit this northeast trend. The reason for this may be the variation in sampling networks.

Aldrin

The distribution of aldrin in samples from the Task 25 study area is characterized by a small number of detections with limited lateral and temporal continuity.

Distribution point plots of aldrin detections exceeding the CRL of 0.070 ug/l are presented in Figures B-83A through B-83D. The limited number and isolated distribution of detections for aldrin precluded the presentation of contoured distribution maps. In the fourth quarter there were three detections of aldrin in wells upgradient of the NBCS. These detections were in samples from Wells 23010, 23140, and 23052. There was also a fourth quarter detection of aldrin in a sample from Well 24192, downgradient of the NBCS soil-bentonite barrier. Aldrin exhibited the widest offpost distribution during the first quarter, with four detections in samples of ground water from the First Creek Pathway. The highest first quarter offpost concentration was 0.29 ug/l, in a sample from Well 37313. There were also several detections of

aldrin in samples collected during the first quarter from wells located in Section 27, upgradient of NWBCS. There was only one detection each for the second and third quarters. There was one fourth quarter detection downgradient of the NWBCS soil-bentonite barrier, in a sample from Well 22017.

Similar to the FY87 data, few concentrations of aldrin were detected during the previous two-year sampling period, and these concentrations varied considerably during this period (PMSO, 1987a, RIC#87320R01). Variations between the FY87 aldrin distributions and those of the previous two years can probably be attributed to the different sampling networks. The difference in the sampling networks also makes it difficult to compare aldrin distributions offpost. Aldrin was detected in two wells downgradient of the NBCS during the fourth quarter FY86, but in FY87, aldrin concentrations in these two wells were below the CRL.

Onpost water quality data generated prior to FY85 (Spaine *et al.*, 1984, RIC#85133R04; Thompson *et al.*, 1985, RIC#86078R01; MKE unpublished data, 1986) indicates similar aldrin distributions as in FY87, however, aldrin concentrations are generally higher than in FY87. Offpost, isolated aldrin concentrations detected prior to FY85 were also higher than in this area in FY87. The Spaine map indicates concentrations up to 4.25 ppb and the first quarter FY84 map indicates a concentration just south of First Creek along the 13/14 section line of 40.0 ppb.

Isodrin, p,p'-DDT and p,p'-DDE

The chlorinated pesticides isodrin, p,p'-DDT, and p,p'-DDE were detected in only a limited number of samples from the study area. Distribution point plots for these compounds are presented in Figures B-84A through B-86D. Generally, the distributions for these compounds demonstrate limited lateral and temporal continuity and are represented by a small number of isolated detections each quarter. Observed concentrations of isodrin ranged from the CRL of 0.060 ug/l to 0.734 ug/l. Isodrin was detected during the first quarter in samples from two wells upgradient of the NBCS, 23057 and 24002, as well as in a second quarter sample from Well 24181.

There were several detections of isodrin in the vicinity of the NWBCS during the four quarters of FY87. The compounds p,p'-DDE and p,p'-DDT exhibited the greatest number of detections for the third and fourth quarters, respectively. DDE was detected in samples from four wells located in the Task 25 study area. The concentrations in these samples ranged from 0.047 to 0.113 ug/l. DDT was detected in samples from seven wells in the vicinity of the NBCS during the fourth quarter, and the concentrations in these samples ranged from 0.146 to 1.10 ug/l.

Isodrin, p,p'-DDT, and p,p'-DDE were not assessed in the localized studies of the previous two years. Comparison of FY87 isodrin, p,p'-DDT and p,p'-DDE distributions with those distributions in the FY86 regional study is difficult since very few, scattered detections are indicated in either study. Generally, concentrations are higher and detections more frequent in FY87, however, this is probably a function of the difference in sampling networks. Isodrin, p,p'-DDT and p,p'-DDE were not analyzed in the FY84 study (Thompson *et al.*, 1985, RIC#86078R01) nor in the Spaine investigation (Spaine *et al.*, 1984, RIC#85133R04). The MKE generalized isodrin distribution map (unpublished data, 1986) indicates higher concentrations in the southeast quarter of Section 27 in 1979 than were found in this section in FY87. These maps also indicate isodrin was detected at the RMA north boundary in 1978, though no detections were apparent in this area in the FY87 study.

5.1.2.8 Volatile Organohalogens

During FY87, within the Task 25 study area, chloroform, trichloroethene, tetrachloroethene, and 1,2-dichloroethane were the most widely detected volatile organohalogens. Other volatile organohalogens detected include: 1,1-dichloroethene, t-1,2-dichloroethene, methylene chloride, carbon tetrachloride, 1,1-dichloroethane, 1,1,1-trichloroethane, and 1,1,2-trichloroethane. The concentrations and distributions of these compounds are summarized below.

Chloroform

Concentrations of chloroform detected during the four quarters of FY87 ranged from the CRL of 1.90 ug/l to greater than 19,400 ug/l. The distribution maps for chloroform are presented in Figures B-78A through B-78D. Isoconcentration lines illustrated on the maps include the CRL, and 10, 50, 100, 1,000, and 10,000 ug/l.

Upgradient of the NBCS the chloroform distribution follows a northeast trend from the Basin F area to the containment/treatment system. This distribution corresponds to the Section 26 Northeastern Pathway. There is also a minor component of transport from the North Plants area in Section 25 to the north-northwest, corresponding to the North Plants Pathway. This minor pathway exhibits samples with fairly low concentrations and is not well defined. It includes monitoring Wells 24081, 24111, 24002, and 24027.

The chloroform distribution is approximately 3,500-ft wide as it enters the study area, decreasing to less than 1,500-ft wide as it approaches the boundary/containment system where it spreads laterally in the direction of First Creek. Located along the axis of the distribution are a group of wells for which samples generally exhibited concentrations exceeding 1,000 ug/l. This group of wells includes 23049, 23057, 23102, and 23004. Well 23179, sampled only during the third quarter, is also located within this pathway and a sample from this well showed the highest observed concentration of chloroform for FY87, greater than 19,400 ug/l. Although this high concentration trend is present each quarter, many of the wells sampled along this pathway exhibit order of magnitude fluctuations in chloroform concentration from quarter to quarter. An example of this is Well 23102. The concentrations for chloroform in the samples from this well ranged from 11.6 to 7,250 ug/l. This significant difference in concentrations is not indicative of natural variations and may be attributable to laboratory or field inaccuracies.

Downgradient of the NBCS the concentrations of chloroform detected in samples collected during the first two quarters of FY87 were generally isolated and did not

indicate a dominant transport pathway in the northern offpost area. Samples collected from newly installed wells during the third and fourth quarters indicated a dominant component of transport for chloroform in the Northern Pathway. The highest concentrations in this transport pathway were exhibited by the third and fourth quarter samples from Well 37367.

The fourth quarter sampling of the newly installed piezometers, immediately downgradient of the soil-bentonite barrier, indicate concentrations in this area as high as 132 ug/l. Stagnant water, trapped between the line of recharge wells and the soil-bentonite barrier, may be responsible for these concentrations. The fourth quarter sample from Well 24194 exhibited the highest concentrations of chloroform detected downgradient of the NBCS.

Consistent, low concentration detections of chloroform in samples from Well 37338, located at the RMA boundary near First Creek, indicate that there is probably some component of chloroform transport along First Creek from the eastern end of the NBCS.

Upgradient of the NWBCS the chloroform contamination trends north-northwest from the southern and eastern boundaries of the Southeast quarter of Section 27, along the Section 26 Western Pathway. During the second quarter sampling, detections of chloroform in samples from Wells 22011 and 22051 indicated the potential for a component of transport along the Section 26 Northwest Pathway.

Concentrations in samples from wells located upgradient of the NWBCS range from the CRL to 130 ug/l. The dominant trend of chloroform concentrations exceeding 50 ug/l is oriented from north to south in north-central Section 27. Well 27068 exhibited the highest mean concentration of chloroform for FY87 within this area. Samples from this well exhibited a mean concentration of 65.5 ug/l, with a range of values from 45.9 to 111 ug/l.

Samples collected from wells located downgradient of the NWBCS indicated a range of concentration values from the CRL to 56.3 ug/l. The concentrations and distributions of chloroform immediately downgradient of the NWBCS appear to be consistent from quarter to quarter.

Chloroform contamination was not assessed in the localized studies conducted in the two years prior to FY87. In the regional onpost RMA study of FY86 (ESE, 1987b, RIC#87253R01), the chloroform distribution and the magnitude of concentrations is similar to FY87. Small variations appear to be related to differences in the sampling networks. From 1975 to 1984, consistent sampling of chloroform was not performed (ESE, 1987b, RIC#87253R01) and therefore due to insufficient data, no comparisons are made.

Trichloroethene

Observed concentrations of trichloroethene (TRCLE) in the study area ranged from the CRL of 1.30 ug/l to 53.2 ug/l. The distribution maps are presented in Figures B-76A through B-76D. Isoconcentration lines used to illustrate the TRCLE distribution include the CRL and 2, 5, 10, and 20 ug/l.

Upgradient of the NBCS the TRCLE distribution is approximately 3,000-ft wide as it enters the study area along the eastern side of the southern boundary of Section 23. The distribution trends north-northeast toward east-central Section 23, where it narrows to approximately 1,200-ft wide and shifts to a more northerly orientation toward the NBCS. The highest concentrations were detected in samples from wells located along the axis of the distribution. The axis of the distribution follows the Section 26 Northern Pathway and is represented by Wells 23052, 23049, and 23095. Of the wells sampled each of the four quarters, Well 23052 exhibited the highest mean concentration of TRCLE. Concentrations in these samples ranged from 13.6 to 39.1 ug/l, with a mean value of 22.3 ug/l.

There were consistent, although isolated detections of less than 2.5 ug/l in samples from Well 23033, located upgradient of the western portion of the NBCS. The detections in these samples were not connected to the main TRCLE distribution; however, they may represent a minor zone of transport through an area of slightly higher T. There were also isolated detections of TRCLE in samples from wells located in Section 24, downgradient of the North Plants. These detections indicate the possibility of a minor pathway for TRCLE trending northwest through south-central Section 24, along the North Plants Pathway.

Downgradient of the NBCS there were only two detections of TRCLE in each of the first two quarters. The third and fourth quarter maps which contain data from newly installed wells in Sections 13 and 14 indicate a more widespread offpost occurrence. Concentrations observed downgradient of the NBCS ranged from the CRL to 7.1 ug/l over the four sampling quarters. There appears to be some limited transport along the First Creek Pathway, but the dominant direction of transport appears to be to the north. The fourth quarter sampling of newly installed piezometers, located just downgradient of the soil-bentonite barrier, indicate comparable concentrations in this area to those observed offpost.

The observed TRCLE concentrations upgradient of the NWBCS for FY87 ranged from the CKL to 10.7 ug/l. The distribution enters the study area along the eastern boundary of Section 27 and trends west-northwest, along the Section 26 Western Pathway. In the central portion of Section 27 the distribution changes direction to the north toward the NWBCS. Wells sampled each quarter which exhibited the highest concentrations of TRCLE include 27024 and 22008. Changes in the apparent configuration of the distribution over the four sampling quarters are due primarily to variations in the sampling network.

Downgradient of the NWBCS there were only limited detections of TRCLE. Second and third quarter samples from Wells 22015 and 22016 exhibited detections of less than 2.2 ug/l.

Comparing the TRCLE distribution from FY87 with that from the regional onpost RMA study of FY86 (ESE, 1987b, RIC#87253R01) shows the distributions are very similar. In the FY86 study, TRCLE concentrations in the southeast quarter of Section 23 do not extend to the NBCS as in the FY87 study. This may be attributed to fewer sampling points in the northeast quarter of Section 23 during the FY86 study. Due to insufficient data, comparisons with other historical data could not be made.

Tetrachloroethene

Observed concentrations of tetrachloroethene (TCLEE) in the study area ranged from the CRL of 2.80 ug/l to 175 ug/l. The distribution maps are presented in Figures B-77A through B-77D. Isoconcentration lines illustrated on the maps include the CRL and 10, 20, 50, and 100 ug/l.

Upgradient of the NBCS, the TCLEE distribution illustrated on the maps enters the study area along the southern boundary of Section 23. The area of occurrence of TCLEE is approximately 3,000-ft wide as it enters the study area, trending north-northeast it diminishes to less than 1,500-ft wide in central Sections 23 and 24, where it shifts orientation toward the north. The distribution spreads laterally in the direction of First Creek and is approximately 3,000-ft wide as it approaches the NBCS.

A plume of higher concentration values is represented by samples from Wells 23007, 23096, 23004, and 24049. This trend follows the Section 26 Northeastern Pathway. This distribution is positioned about a quarter of a mile to the east compared to the higher concentration areas for the other volatile organohalogenes. This difference is probably due to different source area locations for the different compounds. Samples from Well 23007 exhibit the highest average concentration for wells sampled each quarter in this area, 93.4 ug/l. The concentrations for these samples range from 10.6 to 131 ug/l.

Downgradient of the NBCS the first two sampling quarters indicated that the direction of transport offpost was toward the northwest in the First Creek Pathway. Third and fourth quarter sampling of newly installed wells indicated a component of transport along the Northern Pathway. Concentrations downgradient of the NBCS ranged from the CRL to 92 ug/l. This higher concentration was detected in a third quarter sample from Well 37391. The fourth quarter sampling of newly installed piezometers, located just downgradient of the soil-bentonite barrier, indicated concentrations of more than 50 ug/l in this area. This situation is potentially due to stagnant water held against the barrier.

There was only one detection of TCLEE upgradient of the NWBCS during FY87. This detection, 8.39 ug/l, was in a first quarter sample from Well 27045. Subsequent sampling of this well did not confirm the presence of TCLEE. No TCLEE was detected in samples collected downgradient of the NWBCS during FY87.

The TCLEE distribution determined by FY86 regional sampling onpost RMA (ESE, 1987b, RIC#87253R01) is similar to the distribution exhibited by FY87 sampling. Variations may be related to differences in the particular wells sampled during each period. Comparisons with other historical data could not be made due to lack of consistent sampling of TCLEE in earlier years.

1,2-Dichloroethane

Observed concentrations of 1,2-dichloroethane in the study area ranged from the CRL of 2.10 ug/l to greater than 200 ug/l. The distribution maps for 1,2-dichloroethane are presented in Figures B-79A through B-79D. The distribution is characterized with isoconcentration lines of the CRL and 5 and 10 ug/l. Additional contour lines for 100 and 200 ug/l are used where appropriate.

The distribution for 1,2-dichloroethane appears to be consistent from quarter to quarter during FY87. Upgradient of the NBCS the contaminant distribution enters the study area in south-central Section 23. The plume, which varies between

approximately 1,200- and 2,200-ft wide as it traverses Sections 23 and 24, trends north-northeast, shifting to a more northerly orientation as it approaches the NBCS. The contamination, to a limited extent, occurs along the eastern boundary of the northwest quarter of Section 24. The highest concentrations were detected in samples from wells located on the axis of the distribution, represented by Wells 23052, 23095, and 23049. This trend follows the Section 26 Northern Pathway. Samples from Well 23052 exhibited the highest mean concentration for FY87, 119 ug/l. The concentrations in these samples ranged from less than 52.5 ug/l to 260 ug/l.

There was a general increase in concentrations between the first and subsequent quarters. The highest concentration observed in the first quarter was a less than 84 ug/l detection in Well 23052. A sample from the same well exhibited a concentration of over 250 ug/l for the second quarter sampling. This general trend is observed for numerous wells in Section 23.

The concentrations observed in samples from wells located downgradient of the NBCS indicates transport along the First Creek Pathway. Concentrations in this area ranged from the CRL to 18.1 ug/l. The higher concentration was observed in a third quarter sample from Well 37373. Low concentration detections in third and fourth quarter samples from Well 37391 indicate the potential for contaminant transport along the Northern Pathway. The sampling of newly installed piezometers, just downgradient of the NBCS, indicate only limited contamination in this area.

Upgradient of the NWBCS 1,2-dichloroethane appears to have only limited distribution. There are a group of wells located in east-central Section 27 which consistently exhibit low level concentrations of 1,2-dichloroethane. Only Well 27024 was sampled each quarter. Concentrations in these samples ranged from 2.8 to 7.6 ug/l. There were two other isolated detections upgradient of the NWBCS during FY87 and no detections downgradient of the boundary treatment/containment system.

The distribution of 1,2-dichloroethane in the FY87 study is similar to the combined distribution of 1,2-dichloroethane and 1,1-dichloroethane exhibited in the regional, onpost RMA study conducted during FY86 (ESE, 1987b, RIC#87253R01). Variations may be attributed to differences in the sampling networks. Due to an insufficient amount of historical sampling, comparisons with earlier data are not made.

1,1-Dichloroethene

Concentrations of 1,1-dichloroethene detected in the study area ranged from the CRL of 1.10 ug/l to 11.1 ug/l. Distribution point plots are presented in Figures B-87A through B-87D. The detections of 1,1-dichloroethene were most numerous during the first quarter sampling. Table 5.1-1 lists the number of detections for each compound by quarter. There were several detections upgradient of both the NBCS and the NWBCS during the first quarter.

The 1,1-dichloroethene distribution maps from FY86 (ESE, 1987b, RIC#87253R01) and FY87 are similar in that very few detections were found. The only detection in the Task 25 study area in the FY86 study was relatively low and was not found in the same well during FY87 sampling. Comparisons could not be made with other historical data due to an insufficient amount of sampling.

Trans-1,2-Dichloroethene

Concentrations of t-1,2-dichloroethene detected in the study area ranged from the CRL of 2.40 ug/l to 9.03 ug/l. Distribution point plots are presented in Figures B-88A through B-88D. There were several detections of t-1,2-dichloroethene in Section 23 during the first quarter sampling period. There were no detections in the study area for the second or third quarters and only one detection, in Section 23, during the fourth quarter.

Similar to the second and third quarter sampling periods of FY87, no detections of t-1,2-dichloroethene were found in the regional, onpost RMA FY86 study (ESE, 1987b, RIC#87253R01). As with many of the other volatile organohalogenes discussed

previously, insufficient sampling of t-1,2-dichloroethene does not allow for comparisons.

Methylene Chloride

Concentrations of methylene chloride detected in the study area ranged from the CRL of 2.50 ug/l to 129 ug/l. Distribution point plots are presented in Figures B-89A through B-89D. There were a number of detections in the first period as indicated in Figure B-89A. Upgradient of the NBCS there is a trend of detections each quarter from south-central Section 23 toward the 23/24 section line. Samples from the same wells are not included in this pattern each quarter, but it includes Wells 23004, 23052, 23049, 23179, and 24008.

A limited number of methylene chloride detections downgradient of the NBCS are indicated on the point plots. These include one detection each for samples from Wells 37308, 37309, 23205, and 24163.

In the southern and western quarters of Section 27, in the vicinity of the NWBCS, there were numerous detections of methylene chloride during the first quarter. The concentrations in these samples range from the CRL to 32.5 ug/l. Methylene chloride was not detected in samples from Section 27 in subsequent quarters.

Downgradient of the NWBCS there were several detections of methylene chloride during the first quarter, but there were no concentrations exceeding the CRL in subsequent quarters.

The only two detections of methylene chloride found in the Task 25 study area during the regional onpost RMA study of FY86 (ESE, 1987b, RIC#87253R01) are located in Section 23 along the same trend of high concentrations levels exhibited in the FY87 study. The few detections in the FY86 study is probably a result of the small number of wells sampled as compared to that in FY87. The concentrations of methylene chloride in the two wells did decrease from FY86 to FY87, from 196 to 129 ug/l and

from 17.2 to 5.15 ug/l. Comparisons with earlier data cannot be made due to insufficient sampling for methylene chloride in earlier years.

Carbon Tetrachloride

Concentrations of carbon tetrachloride observed in the study area ranged from the CRL of 1.40 ug/l to 20.9 ug/l. Distribution point plots are presented in Figures B-90A through B-90D. Most of the detections for this compound occurred in Section 24, and all were upgradient of NBCS. The greatest number of detections, and generally higher concentrations, were observed during the second quarter sampling.

In the regional study conducted during FY86, the two detections of carbon tetrachloride are located in the northwest quarter of Section 24, upgradient of the NBCS. Similar concentrations were also detected in this area during all four quarters of FY87.

1,1-Dichloroethane

Concentrations of 1,1-dichloroethane observed in the study area ranged from the CRL of 1.20 ug/l to 4.95 ug/l. Distribution point plots are presented in Figures B-91A through B-91D. There are only a limited number of detections for this compound in the study area each quarter. Most of the detections occurred in Section 23 and follow a northwest trend from the southern section line to the 23/24 section line. There were no concentrations of 1,1-dichloroethane exceeding the CRL in the vicinity of the NBCS. There were no detections of 1,1-dichloroethane in the vicinity of the NWBCS during FY87.

1,1,1-Trichloroethane

Concentrations of 1,1,1-trichloroethane observed in the study area ranged from the CRL of 1.10 ug/l to 13.9 ug/l. Distribution point plots are presented in Figures B-92A through B-92D. This compound was detected upgradient of the NBCS, in Section 24, in a limited number of samples. This compound was not detected in the area of the Task 25 study during the onpost RMA FY86 study (ESE, 1987b,

RIC#87253R01). This difference, however, could be due to differences in the sampling network.

1,1,2-Trichloroethane

Concentrations of 1,1,2-trichloroethane observed in the study area ranged from the CRL of 1.00 ug/l to 6.1 ug/l. The distribution point plots are presented in Figures B-93A through B-93D. This compound was detected sporadically in samples from wells located both upgradient and downgradient of the NBCS. 1,1,2-Trichloroethane was not detected in the area of the Task 25 study during the onpost RMA FY86 study (ESE, 1987b, RIC#87253R01).

5.1.2.9 Volatile Aromatics

The volatile aromatic compounds benzene, chlorobenzene, toluene, ethylbenzene, m-xylene, o-xylene, and p-xylene were detected in the study area during FY87. All of these compounds are presented in distribution point plots in Appendix B. The isolated nature of the detections of these compounds precluded contouring. The concentrations and distributions of these contaminants are summarized below.

Benzene

Observed concentrations of benzene detected in the study area ranged from the CRL of 1.34 ug/l to 26.2 ug/l. The distribution point plots for benzene are presented in Figures B-94A through B-94D.

The distribution of benzene upgradient of the NBCS occurred as isolated detections primarily along the Section 26 Northern Pathway from south-central Section 23 toward the 23/24 Section line. There were a number of detections in the vicinity of the NBCS over the four quarters.

Downgradient of the NBCS there was only one detection of benzene during the first and second quarter samplings. This detection was exhibited by a sample from Well 37320, located near the northern boundary of Section 13. For the third quarter, the

sampling of newly installed alluvial aquifer wells in Section 13 indicated widespread low concentrations of benzene in offpost samples. However, fourth quarter sampling did not verify the extent of the third quarter distribution.

There was one detection of benzene upgradient of the NWBCS in Section 27 and several isolated detections of benzene downgradient of the NWBCS over the four quarters of sampling.

Benzene was detected in south-central Section 23 during the onpost RMA FY86 study (ESE, 1987b, RIC#87253R01). These concentrations were similar to those detected in that area during the Task 25 study. Benzene was not analyzed for on a regular basis during historical studies and therefore no meaningful comparisons can be made.

Chlorobenzene

Observed concentrations of chlorobenzene in the study area ranged from the CRL of 0.580 ug/l to 180 ug/l. The distribution point plots for chlorobenzene are presented in Figures B-95A through B-95B. The distribution of chlorobenzene in samples collected from wells upgradient of the NBCS was limited during the first three quarters of sampling. There was only one detection of chlorobenzene during the first three quarters. A second quarter sample from Well 23120 exhibited a chlorobenzene concentration of 15.4 ug/l. The fourth quarter samples exhibited a more widespread distribution of the contaminant. There were eight detections of chlorobenzene upgradient of the NBCS during the fourth quarter. The concentrations of these samples are relatively high, ranging from 1.20 to 180 ug/l.

Downgradient of the NBCS there were only limited detections of chlorobenzene during the first two quarters. The third quarter distribution is characterized by numerous detections in the First Creek and Northern Pathways in Sections 13 and 14. The fourth quarter distribution for chlorobenzene indicates numerous detections along the First Creek Pathway in Section 13. There were also two detections in the Northern Pathway, but it appears to be a minor pathway for chlorobenzene.

There were no detections of chlorobenzene upgradient of the NWBCS during FY87. There were, however, numerous detections of chlorobenzene downgradient of the NWBCS during the four quarters of sampling. The concentrations in samples from this area ranged from the CRL to 16.5 ug/l.

Toluene

Observed concentrations of toluene in the study area ranged from the CRL of 1.21 ug/l to 48.4 ug/l. Distribution point plots are presented in Figures B-96A through B-96D.

Upgradient of the NBCS detections of toluene occur predominantly in samples from wells located in Section 23. There were more detections of toluene during the first quarter sampling than during the subsequent quarters, when there were only one or two detections in the study area per quarter.

There was one isolated detection of toluene downgradient of the NWBCS during FY87 (first quarter).

Ethylbenzene, m-Xylene, o- and/or p-Xylene

Distributions of ethylbenzene, and the xylene compounds are presented in point plots in Figures B-97A through B-99D. Ethylbenzene was most widely detected during the fourth quarter sampling and several of these detected concentrations were in the vicinity of the NBCS. Concentrations during FY87 ranged from the CRL of 0.620 ug/l to 3.69 ug/l. Concentrations of m-xylene ranged from the CRL of 1.04 ug/l to 3.82 ug/l. Concentrations of o- and/or p-xylene ranged from the CRL of 1.34 ug/l to 4.4 ug/l.

Chemical data presented by Spaine *et al.* (1984, RIC#85133R04) indicate no concentrations of volatile aromatic compounds associated with the area of the Task 25 study. The onpost RMA FY 86 study (ESE, 1987b, RIC#87253R01) detected volatile aromatic compounds in the south-central portion of Section 23. These concentrations

were between 10 and 100 ug/l and are similar to the concentrations detected in that area during FY87. There were more numerous detections of volatile aromatic compounds during the Task 25 study but this is due, to some extent, to differences in the density of the sampling networks.

5.1.2.10 Inorganics

The elements arsenic, chloride, and fluoride were analyzed as part of the Task 25 program. These are naturally occurring constituents that exhibit excess concentrations as contaminants. The concentrations and distributions are summarized below. As a point of comparison, concentrations from alluvial wells sampled upgradient of the study area are presented in Table 5.1-3 for each element. These wells are located in the southern sections of RMA and immediately offpost to the southeast of RMA. These data are not intended to define background concentrations but are presented for comparison.

Arsenic

Arsenic concentrations in samples from wells monitored in the Task 25 study area ranged from less than the CRL of 2.50 ug/l to 45.2 ug/l during FY87. The arsenic concentration distribution maps are presented in Figures B-82A through B-82D. The isoconcentration lines presented on the maps include the CRL, and 5, 10, and 20 ug/l.

Arsenic is a naturally occurring element. For purposes of comparison, arsenic data are presented for samples collected from a well located upgradient of the study area. Table 5.1-3 presents these arsenic concentrations, which are less than 3.90 ug/l. These data are not presented to define background concentrations and actual background values may be more variable than Table 5.1-3 indicates.

The dominant arsenic distribution, which includes the high concentration of 45.2 ug/l, occurs in the eastern half of Section 23 and partially along the western boundary of Section 24. The distribution, which is approximately 2,500-ft wide at its widest point, trends from the south-central border of Section 23 north-northeast toward the NBCS.

Table 3.1-3. Representative Concentrations For Naturally Occurring Constituents in Upgradient Alluvial Wells
(Values are in µg/l).

Analyte	Well Number			Alluvial Well (Approximately 0.5 miles south east of RFA)	Analyte	µg/l Well Number			Range From Upgradient Wells
	3" Well Spring 1986	3" Well Spring 1987	3" Well Summer 1987			12001	11001	06002	
Chloride	46,200	45,200	46,000	*	Chloride	36,000	52,000	60,000	36,000 - 60,000
Fluoride	<1,200	<1,200	<1,200	1,000	Fluoride	600	570	660	570 - <1,200
Arsenic	<1.9	<1.9	*	*	Arsenic	*	*	*	<1.9
Sulfate	139,000	106,000	98,200	46,000	Sulfate	63,000	132,000	43,000	43,000 - 138,000
Calcium	5,560	3,850	4,680	51,000	Calcium	67,000	139,000	112,000	51,000 - 139,000
Potassium	106,000	127,000	131,000	*	Potassium	*	*	*	3,850 - 5,700
Sodium	23,200	25,600	23,300	36,000	Sodium	44,000	68,000	60,000	36,000 - 131,000
Magnesium	6,600	7,260	8,080	9,200	Magnesium	*	*	*	9,200 - 25,600
Nitrogen	112	72.0	<20.1	8,300	Nitrogen	3,500	700	22,900	700 - 22,900
Zinc	<5.20	<5.16	<5.16	*	Zinc	*	*	*	<20.1 - 112
Cadmium	<18.5	<18.6	<18.6	*	Cadmium	*	*	*	<5.20
Lead	<6.00	*	18.2	*	Lead	*	*	*	<18.6
Chromium	<7.96	<7.96	7.96	*	Chromium	*	*	*	<6.00 - 18.2
Copper	<0.240	<0.240	<0.240	*	Copper	*	*	*	<7.96
Mercury				*	Mercury	*	*	*	<0.240

* Not analyzed.
 ** Irrigation well, 70 ft deep, in TDS Box, Section 17 (McCarthy et al., 1964).
 *** Alluvial wells near southern boundary of RFA, samples collected 1975 and 1976 (Army, RIG#2160R12).
 Source: ESE, 1986.

The spatial distribution of the CRL, and 5 and 10 ug/l isopleths are very consistent for all four quarters. The 20 ug/l isopleth present in the first three quarters is absent in the fourth quarter.

The highest arsenic concentrations throughout FY87 are consistently detected in Wells 23095, 23179, and 23049, in south-central Section 23, north of Basin F. The samples from Well 23049 contained the highest concentrations of arsenic on average. The mean of the first three quarterly concentrations for Well 23049 was 41.3 ug/l, but the fourth quarter maximum of 11.3 ug/l is substantially less.

Arsenic detections in samples collected downgradient of the NWBCS in Sections 13 and 14 range from the CRL to 13.6 ug/l. The highest concentration was detected in a first quarter sample from Well 37313. The distribution in this area is generally characterized by isolated detections, except in the first quarter, when a northwest trending distribution along the First Creek Pathway is apparent. Most of the detections occur in Section 14 along the First Creek Pathway.

Upgradient of the NWBCS, the portion of the distribution with relatively high concentrations enters the study area near the midpoint of the eastern boundary of Section 27. The distribution trends northwest toward the NWBCS, along the Section 26 Western Pathway. There is little change in the location of the 2.5, 5, and 10 ug/l isopleths from quarter to quarter. The maximum concentrations occur in the central and east-central area of Section 27, with a high concentration value of 20.8 ug/l. Well 27024 is located in the high concentration area of the distribution, and was sampled all four quarters. The concentrations for arsenic in samples from Well 27024 range from 16.6 to 19.6 ug/l.

Samples from wells located downgradient of the NWBCS exhibited concentrations of less than 10 ug/l, except for the first quarter sample from Well 22018 which exhibited

a value of 21.8 ug/l. Other than this exception, the arsenic concentrations and distribution downgradient of the NWBCS were consistent from quarter to quarter.

Fluoride

Detectable concentrations of fluoride in the study area for FY87 range from the CRL of 1.00 milligram per liter (mg/l) to greater than 13.4 mg/l. The fluoride distribution maps are presented in Figures B-81A through B-81D. The database in Appendix A is provided in units of ug/l. The maps are contoured in units of mg/l, for simplicity of presentation. Fluoride is a natural constituent of ground water. For comparative purposes, fluoride data are presented for samples collected from wells upgradient of the study area. Fluoride concentrations in these samples range from 0.570 to 1.00 mg/l (Table 5.1-3). Average values of 1 mg/l have been reported in the literature for regional fluoride concentrations (Stollar and van der Leeden, 1981, RIC#81293R05). The fluoride distribution maps are contoured using 2, 5, and 10 mg/l isoconcentration lines.

The fluoride distribution upgradient of the NBCS is broad and diffuse. There is a narrow plume of fluoride rich water which enters the study area downgradient of Basin F, trends northeast to the 23/24 section line, and then shifts orientation due north toward the NBCS. This trend corresponds to the Section 26 Northern Pathway. Sampled wells with relatively high concentrations of fluoride include 23049, 23095, 23052, 23004, and 23160. Concentrations in samples from Well 23095 ranged from 9.54 to 9.69 mg/l for the first three quarters. During the fourth quarter sampling period the concentration could only be reported as less than 12.2 mg/l. A 10 mg/l isoconcentration line was added to the third quarter map due to the more than ten-fold increase in concentration of fluoride in the sample from Well 23052. This value was confirmed by a relatively high concentration (9.45 mg/l) in a sample from the same well during the fourth quarter. There was also a four-fold increase in fluoride concentration in samples from nearby wells 23102 and 23057. Other than this one exception, fluoride concentrations in samples across the study area appeared to be relatively stable from quarter to quarter for FY87.

The pattern of fluoride distribution downgradient of the NBCS is broad and diffuse, with many detections in the First Creek Pathway exceeding 2 mg/l. Concentrations downgradient of the NBCS ranged from the CRL up to 4.77 mg/l. The higher concentrations were detected in fourth quarter samples from the newly installed piezometers just downgradient of the soil-bentonite barrier.

The highest concentrations over the four sampling quarters were detected in samples from Well 37339, which is located at the RMA boundary in south-central Section 14. The fluoride concentrations in these samples ranged from 3.94 to 4.65 mg/l.

Upgradient of the NWBCS concentrations of fluoride ranged from approximately 2 to 3 mg/l. During the first two sampling quarters, relatively high concentrations were detected in samples from wells located in Section 22 and the northeast quarter of Section 27. During the third and fourth quarter sampling events, the 2 mg/l concentration line shifted southward to include much of the eastern half of Section 27.

Downgradient of the NWBCS soil-bentonite barrier, the concentrations of fluoride were in the 2 to 3 mg/l range. To the southwest, downgradient of the hydraulic barrier, the concentrations are lower and do not exceed 1.90 mg/l.

A review of the maps for the previous two years (PMSO, 1987a, RIC#87320R01 and 1987b, RIC#88054R01) indicates similar concentrations and distribution for fluoride. Variations may be attributable to the differences in the monitoring networks employed. A slightly different contour interval was used previously, but the positions of the 2 mg/l isoconcentration lines are comparable. Fluoride distribution maps in the vicinity of the NBCS from 1977 through the first quarter FY85 (Thompson *et al.*, 1985, RIC# 86078R01) differ from the FY87 maps in that the highest concentrations are found in the north-central part of Section 23 and concentrations decrease to the southeast. During the second quarter FY84, and continuing into subsequent years

including FY87, the highest concentrations shift to a northeast trend extending from downgradient of Basin F to the center of Section 23 and then northward to the NBCS. On maps from 1983 and 1984 sampling periods higher concentrations offpost RMA are typically present downgradient of the western portion of the NBCS. FY87 data indicates concentrations in this area have decreased.

Chloride

Chloride concentrations in the alluvial aquifer ranged from 32 to 9,500 mg/l during FY87. Chloride distribution maps are presented in Figures B-80A through B-80D. The maps are contoured with 250, 500, 1,000, 2,000, and 5,000 mg/l isoconcentration lines.

The dominant chloride distribution in Sections 23 and 24 trends from the general vicinity of Basin F to the NBCS. The centerline of the distribution enters the study area in south-central Section 23, trending northeast toward the 23/24 section line, where it shifts orientation directly north toward the NBCS. This trend corresponds to the Section 26 Northern Pathway. The chloride distribution spreads widely across Section 23 to the west, but occupies only a thin strip in northwest Section 24. The maximum concentrations of 5,400 to 9,500 mg/l were detected in samples from Wells 23095, 23049, and 23052. The mean maximum concentration value for all four quarters was 6,800 mg/l. The highest concentration, 9,500 mg/l, was detected in a fourth quarter sample from Well 23052. The distribution of chloride retains the same general configuration, from quarter to quarter, with no apparent temporal changes in concentration or spatial distribution.

The chloride distribution downgradient of the NBCS is not well defined, and exhibits concentrations ranging from less than 250 to 2,220 mg/l. Samples from Well 37339 in south-central Section 14 consistently exhibit the highest concentrations in the offpost study area with a range of concentrations from 1,990 to 2,220 mg/l. During the first two quarters, most of the chloride-rich water is located in the southeast quarter of Section 14, with some occurrences in the southwest quarter of Section 13. The main

pathway of chloride transport appears to be along the First Creek Pathway. In the third and fourth quarters, samples from new wells installed in Section 13 indicated that a component of the chloride distribution follows the Northern Pathway. First and third quarter samples from Well 37327, which is located near the eastern border of Section 13, exhibits concentrations exceeding 250 mg/l. It is uncertain if these concentrations are continuous with the distribution to the west.

Upgradient of the NWBCS in Sections 22 and 27 the chloride distribution exhibits relatively low maximum concentrations, compared to wells upgradient of the NBCS. The average maximum concentration over the four quarters of FY87 is 890 mg/l. Most of the chloride transport appears to trend northwest from the 27/26 section line to the NWBCS. There is a component of transport north from the southern boundary of Section 27. The northern edge of the distribution in Section 22 is continuous with the distribution in Section 23 at the 250 mg/l concentration level. The maximum chloride concentration downgradient of the NWBCS was 728 mg/l in a sample from Well 37332.

Chloride distribution maps in the vicinity of the NBCS from the previous two years (PMSO, 1987a, RIC#87320R01) exhibit similar concentrations and contaminant distribution. In the vicinity of the NWBCS, the chloride distribution during the previous two years is similar except for upgradient of the system, where the contaminant appears to follow two more distinct pathways than it does in FY87. One follows the Section 26 Western Pathway and the other follows the Section 26 Northwestern Pathway. Chloride distribution maps constructed from various sampling periods between 1977 and 1984 (Thompson *et al.*, 1985, RIC#86078R01) exhibit similar distributions to FY87, though the maximum concentration is generally lower. Throughout the majority of the sampling periods, the maximum concentration doesn't exceed 5000 ppm. Similar to the FY87 maps, higher chloride concentrations migrate further toward the NBCS during each subsequent period.

5.1.3 CONTAMINATION TRENDS

The contoured distribution maps exhibit zones of high concentrations of contaminants in the vicinity of the NBCS and NWBCS. These zones represent primary contaminant migration pathways that correspond to paleochannel trends and associated alluvial sediments of relatively high transmissivity. A few of the contaminants discussed above are transported along all of these primary migration pathways. DIMP and chloride are an example of this. These contaminants are the most widespread both onpost and offpost. Several of the contaminants, such as chloroform and DBCP, are limited in occurrence and are not detected in wells sampled along some of the transport pathways. This section will summarize some of the apparent trends in the distribution of alluvial contaminants.

5.1.3.1 Dominant Distribution Patterns

Contaminant distribution patterns have been evaluated for three areas: Sections 23 and 24, between Basin F and the NBCS; Sections 13 and 14, downgradient of the NBCS; and Sections 22 and 27, upgradient of the NWBCS.

Sections 23 and 24

Two dominant distributions are observed in Sections 23 and 24. The first is characterized by the chloride distribution and is centered along the bedrock channel in south-central Section 23, north-northeast from Basin F. This has been labelled the Section 26 Northern Pathway. Most of the contaminants follow this channel to the 23/24 section line where they are diverted north into a zone of increased transmissivity by the influence of the pumping wells at the NBCS. The second pattern, characterized by the DBCP distribution, parallels the bedrock channel in Section 23, but is located 1/4 mile to the east. This pathway has been labelled the Section 26 Northeastern Pathway.

The distributions of DIMP, fluoride, endrin, dieldrin, trichloroethene, and chloroform have minor secondary contaminant contributions to Section 24 from the North Plants

area. This distribution has been labelled the North Plants Pathway. For DIMP, this distribution merges with the contamination in Section 23.

Sections 13 and 14

Two primary contaminant distribution patterns and two secondary patterns are observed in Sections 13 and 14, downgradient of the NBCS. From the NBCS near Peoria Street and 96th Avenue, one primary flow pathway follows the First Creek paleochannel to the northwest. This is the First Creek Pathway, as described previously. The position of the other primary pathway becomes apparent in the third and fourth quarters as a result of the increased density of monitoring wells in Section 13. This pathway follows a paleochannel to the north along the east side of Peoria Street, and has been discussed previously as the Northern Pathway. A region of unsaturated alluvium exists between them.

Most of the contaminants, chloride, fluoride, tetrachloroethene, DIMP, COS, trichloroethene, 1,2-dichloroethane, and dieldrin, have components of their distribution in both of these primary flow pathways. Two compounds, chloroform and DBCP, have observed concentrations only in the Northern Pathway. DCPD, 1,4-dithiane, and 1,4-oxathiane are detected offpost only in samples from the First Creek Pathway.

There are two secondary pathways offpost that are less frequently observed. The first is a northerly flow from the east end of the NBCS through the central region of Section 13, as exhibited by endrin. The second is a north-northwest flow from the western end of the NBCS, as characterized by the DIMP distribution in that area. These are the East 96th Avenue Pathway and West 96th Avenue Pathway, respectively, and have been discussed previously in reference to individual contaminants.

Sections 22 and 27

Three distribution patterns are evident in Sections 22 and 27. Several prominent unsaturated areas within the alluvial aquifer control the flow upgradient of the NWBCS. The first has been described previously as the Section 26 Northwest Pathway. This pathway transports contaminants from the Basin F vicinity through the southeast corner of Section 22 and exhibits consistent detections of dieldrin, chloride, fluoride, as well as sporadic detections of endrin and chloroform. The second distribution pattern, described as the Section 26 Western Pathway, transports contaminants from the Basin C, D, and E area through the east-central boundary of Section 27. The highest concentrations upgradient of the NWBCS are evident within this trend. Samples exhibit detectable concentrations of dieldrin, chloroform, DIMP, trichloroethene, 1,2-dichloroethane, DBCP, COS compounds, and oxathiane, as well as elevated concentrations of chloride and fluoride. The third flow path, described as the Southern Basins Pathway, transports contaminants from the south across the southern boundary of Section 27. This pathway contributes significantly to the distribution of chloride, chloroform, dieldrin, endrin, and fluoride. Concentrations of contaminants are relatively low in samples from wells located immediately downgradient of the NWBCS. The relatively low density of offpost wells in this area does not permit the definition of offpost pathways, if they exist.

5.1.3.2 Factors Influencing Distribution

Numerous factors influence the spacial and temporal distribution patterns demonstrated by the ground-water contaminants in the study area. The most significant of these factors are discussed below.

Physical and Chemical Behavior of the Contaminants

The different pathways followed by different contaminants, as represented by the distribution maps, is related primarily to the different source areas for individual contaminants. The lateral extent of contamination is directly related to the chemical and physical properties of the individual contaminants.

Two important properties that influence fate and transport of contaminants are volatility, as quantified by Henrys Law Constant (K_H) and sorption, quantified by the partition coefficient (K_d). For the saturated ground water environment, K_H is relatively unimportant, except along the capillary fringe. Figure 5.1-2 is a plot of $\log K_H$ versus $\log K_d$ for RMA target analytes. Chemicals such as benzene and trichloroethene, that appear in the upper right of the plot, are volatile and moderately sorbed. Those to the lower right, such as endrin and dieldrin, are strongly sorbed to solids and are not significantly volatile. DIMP, 1,4-oxathiane, and chloride, that appear in the lower left, are poorly sorbed and of insignificant volatility. The position of each contaminant in Figure 5.1-2 indicates the relative likelihood for sorption to occur, and is therefore indicative of relative mobility in the saturated zone. Compounds can be ranked according to their relative mobility in the saturated zone, such as: chloride > DIMP > DBCP > DCPD > dieldrin.

DCPD, trichloroethene, 1,4-oxathiane, 1,4-dithiane, DIMP, 1,2-dichloroethane, and COS follow the Section 26 Northern Pathway and are labelled in Figure 5.1-2 with an "N." The two contaminants that follow the Section 26 Northeastern Pathway, endrin and DBCP, are labelled with an "NE". Three compounds that follow both pathways, chloroform, dieldrin, and tetrachloroethene, are labelled with both "NE" and "N." Figure 5.1-2 illustrates that compounds associated with each pathway exhibit a variety of characteristics. This may indicate that the location of source areas has dominant influence over contaminant distributions. However, the chemical and physical characteristics of each compound will influence the extent of its lateral and vertical transport.

Certain contaminants, such as DCPD, detected in offpost samples are distributed only in the First Creek Pathway, while contaminants such as chloroform and DBCP occur primarily in the Northern Pathway offpost. The offpost configurations of these plumes are probably closely related to the particular source areas of these contaminants and the corresponding transport pathways. The present day distributions of these contaminants are probably related to their distributions prior to

the installation of the NBCS. After the boundary system became operational, it is expected that any residual contamination in the downgradient sediments would gradually be leached from the aquifer system. The rate of leaching is dependent upon the characteristics of the sediments and soils in question, and the volume of water flowing through the aquifer. As contaminants are flushed from the system, the higher concentration areas of the plume will occur further to the north. The situation that is presently demonstrated in the offpost area is that the highest concentrations of ground-water contamination occur 1/4 to 1/2 mile north of the RMA boundary.

Based on the contaminant distribution maps, several of the analytes, 1,4-oxathiane, 1,4-dithiane, COS, DIMP, dieldrin, endrin, and chloride, appear to have spread laterally in Section 23 more than the remainder of the compounds. All of these compounds exhibit different physical and chemical characteristics, as illustrated by Figure 5.1-2. Chloride, DIMP, COS, 1,4-oxathiane, and 1,4-dithiane are relatively mobile. Endrin and dieldrin are much more likely to be sorbed to the solid phase. When contaminants exhibit different physical and chemical properties but similar distribution patterns, similar sources but different histories may be indicated.

Although the pathway followed by a contaminant is not controlled by its chemical properties, the travel time along the pathway is controlled by the affinity of contaminants for solid mineral surfaces and naturally occurring organic carbon. Sorption of contaminants to aquifer solids retards their rate of movement relative to ground-water flow velocity. The greater a compound's attraction to aquifer solids, the greater the retardation with respect to ground-water flow. This process causes contaminant leaching to be a gradual process. Contaminants which are relatively mobile, such as chloride and DIMP, exhibit the most laterally extensive distributions and have travelled the greatest distance from the source areas. Chloride and DIMP are detected in samples representing all of the dominant and minor pathways. Highly sorbed contaminants such as dieldrin and endrin have not travelled as far from source areas, and are generally detected in samples from offpost wells that are located within 1/2 mile of the boundary. The temporal and spatial patterns of contaminant

introduction to the alluvial aquifer are not precisely defined by this investigation, but are necessary to fully quantify contaminant mobility using observed ground-water distributions.

Vertical Distribution

The concentration of chloride, a major solute, varies from less than 250 mg/l (U.S. EPA Secondary Maximum Contaminant Level) to more than 8,000 mg/l in the alluvial aquifer. For most dissolved inorganic salts and some organic salts, solution densities increase with total dissolved solids. For chloride salts, regardless of whether the counter cation is H^+ , Na^+ , K^+ , Mg^{++} , Ca^{++} , or others, the specific gravity of an 8,000 mg/l chloride solution is about 1.01. For comparison, this is nominally 1 percent more dense than a 250-mg/l chloride solution. Surface waters will stably stratify when densities differ by only 0.1 percent, although rapidly flowing ground water in a porous medium is unlikely to stratify to the same extent. However, dense chloride-rich waters would probably follow a deeper path in the aquifer than low chloride concentration waters, and may be retained in shallow bedrock depressions. Indeed, the high chloride concentration correlates well with bedrock lows. Dissolved contaminants associated with high concentration chloride waters will also follow the deeper pathway taken by chloride, though transport will be variably retarded by sorption for these compounds. Comparison of distribution maps indicate that the elevated concentrations of many of these organic compounds correlate very well with the distribution of elevated chloride. The potential exists for vertical as well as horizontal components to the contaminant distributions. The vertical hydraulic gradient, as discussed earlier in this report, is generally downward, from the alluvial aquifer to the Denver Fm. This interaction may result in the transport of contaminants into the Denver Fm. The presence of dense chloride-rich waters within depressions in the bedrock surface may enhance downward migration of contaminated alluvial water into the Denver Fm. Chloride, however, is a conservative contaminant. It is minimally adsorbed by aquifer materials and is generally transported at the same velocity as ground-water flow. By comparison, organic contaminants are adsorbed to aquifer materials by varying degrees and therefore their transport is retarded relative

to ground-water flow velocity. The interaction between the alluvium and Denver Fm will be addressed in Section 5.3.

Temporal Variation

Most of the apparent changes in spatial distribution of contaminants between quarters are attributable to changes in the network of wells being sampled. Installation of monitoring wells offpost in Section 13 in time for the third and fourth quarter sampling resulted in the extension of contours at least 1/2 mile beyond former limits. Wells installed between the NBCS and the 400 series recharge wells resulted in the addition of several high concentration contours along the barrier for many compounds. This situation is probably the result of contaminated water being retained in a stagnant condition directly downgradient of the barrier.

Temporal changes in concentrations of analytes have no clear pattern that can be attributed to seasonal recharge and dilution, or contaminant degradation and attenuation. Generally, the distribution maps are consistent from quarter to quarter except where noted in the text. The inherent variability in sampling technique and laboratory analysis is probably responsible for the minor fluctuations in concentrations.

5.1.4 INFLUENCE OF THE NBCS

A description of the NBCS and its operation is presented in the Introduction, Section 1.1.1. The NBCS was constructed to withdraw, treat, and recharge ground water flowing through the alluvium and upper Denver Fm at the RMA north boundary.

Analysis of the NBCS and recommendations to improve its effectiveness are included in the North Boundary System Component Response Action Assessment Final Report, Task 36 (ESE, 1989a, RIC#89103R01). This report discusses several reasons for observed contamination downgradient of the system. Primarily due to inadequate recharge downgradient of the pilot portion of the system, high vertical hydraulic gradients downward are induced upgradient of this portion of the system. This

increases the potential for migration in weathered claystone and sandstone beneath the soil-bentonite barrier. Inadequate recharge downgradient of the system is believed to be caused by installation of recharge wells in fine-grained and cemented material and mechanical clogging by carbon fines. The shallowness of the pilot portion of the barrier, which penetrates only 1 to 2 ft into bedrock, also enhances the migration potential beneath the barrier. Furthermore, the NBCS report indicates dewatering wells in the alluvium upgradient of the pilot portion of the system are not intercepting natural flows, thus allowing for contaminant bypass.

The influence of the NBCS on contaminant concentrations and distributions is examined in the following discussions of trends in historically monitored wells and comparison of upgradient and downgradient contamination.

5.1.4.1 Trends In Historically Monitored Wells

An assessment of temporal contaminant concentration trends may be accomplished by evaluating the record of water quality analyses for wells with long sampling histories. Discussion of five wells monitored by the Army since 1978, and evaluated for temporal concentration trends in previous reports (Thompson *et al.*, 1985, RIC#86078R01; and PMSO, 1987a, RIC#87320R01), are presented below. These wells, located downgradient of the NBCS, are: 23043, 23047, 37308, 37309, and 37313. The Operational Assessment Reports (Thompson *et al.*, 1985, RIC#86078R01; and PMSO, 1987a, RIC#87320R01) evaluated the temporal trends for DIMP and DBCP in samples from these wells. Long-term trends were also evaluated for DIMP, DBCP, DCPD, and dieldrin in the Task 36 report. The assessment presented here includes DIMP and DBCP, as well as dieldrin, COS, and trichloroethene. This group of contaminants was chosen because they represent a range of physical and chemical properties. Some of these compounds are only sporadically detected or are not detected in some of the samples.

Concentration-versus-time plots for DIMP, DBCP, dieldrin, COS, and trichloroethene, for samples collected from each of the wells specified above, are presented in Figures

B-119A through B-123. The general trends for each of these contaminants is discussed below. Each of the plots presents data for FYs 85, 86, and 87. Historical values for FY79 through FY84 are presented in previous reports (PMSO, 1987a, RIC#87320R01 and 1987b, RIC#88054R01). Observed values that are less than the detection limit are presented as 0.00 on the plots. Where possible, comparison of data for DIMP and DBCP collected after 1985 with historical data is also presented.

The long-term trends presented in previous reports are generally consistent with the shorter-term trends presented in this report. For the wells evaluated, DIMP and DBCP concentrations reported since 1978 generally have indicated a declining trend. The short-term trends for DIMP and DBCP are more difficult to assess because of limited data. Although generally consistent with long-term trends, stable or slightly increasing concentrations have been noted in some wells since 1985. Because of the short time frame, these instances may be due to natural variability and should not be used in lieu of long-term trends to evaluate the NBCS effectiveness.

The reliable sampling record of only a few years for dieldrin, COS, and trichloroethene, however, is probably not long enough to allow evaluation of long-term trends. Where detected, dieldrin, COS, and trichloroethene concentrations generally exhibited declining or stable concentrations from 1985 through 1987. Short-term trends should not be considered as reliable an indicator of system effectiveness as long-term trends and may be of limited value in the absence of historical data.

Well 23043 is located just west of D Street and just south of 96th Avenue. DIMP concentrations observed in samples collected from Well 23043 ranged from a high of 807 ug/l in a sample collected during July 1978 to a low of 15.0 ug/l in a sample collected during the spring of 1987. Samples collected between 1978 and 1985 exhibited an average concentration of approximately 250 ug/l with significant fluctuations in concentrations. A concentration versus time plot for DIMP is presented in Figure B-119A. The plot indicates variable DIMP concentrations in the samples collected during the last three years, although the trend since 1986 is for

generally decreasing concentrations in samples from this well. This is consistent with the long term decreasing trend presented in the Task 36 Report (ESE, 1989a, RIC#89103R01). DBCP concentrations observed in samples from this well ranged from a low of less than the CRL of 0.130 ug/l, reported for samples collected during the first two quarters of FY87, to a high of 8.09 ug/l, detected in a sample collected in September 1979. DBCP values reported for samples from Well 23043 have varied by an order of magnitude over the sampling history of the well. The apparent trend since 1985 has been generally decreasing values as shown in Figure 119B.

Observed dieldrin concentrations in samples from Well 23043 have varied less than an order of magnitude for FY85 through FY87 (Figure B-119C). Concentrations in these samples ranged from a low of 0.070 ug/l reported in the winter (second quarter) 1987 to a high of 0.70 ug/l reported in summer 1985. The general trend for dieldrin concentrations in this well appears to be generally decreasing since summer 1985, although the trend is difficult to assess due to changes in CRLs. Over the course of the last three years of sampling, the highest CRL for the COS has decreased from 20 ug/l to 4.70 ug/l. Concentrations of COS in samples from Well 23043 range from a low of less than the highest CRL for these compounds during the winter and spring of 1985 to a high of 80.2 ug/l during fall 1986 (Figure B-119D). During FY87 there was an approximately five-fold increase in concentrations from the first to the fourth sampling quarters. It is difficult to assess the long term trends for these compounds, however, from this limited data set. Trichloroethene has never been detected in samples from Well 23043.

Well 23047 is also located just south of 96th Avenue and approximately 1,100 ft west of D Street. DIMP concentrations in samples from Well 23047 have varied by up to two orders of magnitude since 1978. The highest concentration reported to date was a value of 3,510 ug/l observed in a sample collected in July 1978. Numerous values of less than 100 ug/l have been reported since 1978. Concentrations have exhibited overall a substantial downward trend since 1978 but have increased slightly since 1985 (Figure B-120). DBCP concentrations in samples from this well have generally been

below the CRL, which has decreased from 0.200 ug/l for the historical data to 0.130 ug/l for the more recently collected data. Concentrations of dieldrin and trichloroethene exceeding the CRL have never been reported for samples from this well. Concentrations of the COS have not exceeded the highest CRL for these compounds during the sampling history of Well 25047.

Well 37308 is located offpost, approximately 500 ft north of the RMA north boundary along Peoria Street. Concentrations of DIMP detected in samples from Well 37308 have varied by an order of magnitude over the sampling history of the well. The highest value reported to date was 1,090 ug/l in a sample collected in August 1978. The lowest value reported was 40 ug/l in a sample collected during summer 1987 (fourth quarter FY87). Figure B-121A indicates a general decrease in DIMP concentrations since winter 1986. This is consistent with the long term trend presented in Task 36. Historical concentrations of DBCP in samples from Well 37308 (collected between 1977 and 1985) have generally been below the CRL. As noted above, the CRL has decreased from 0.200 to 0.130 ug/l. For samples collected from fall 1985 through winter 1987 the values reported exceeded the CRL and ranged from 0.210 to 0.876 ug/l (Figure B-121B), and a general declining trend can be observed from the graph. Concentrations of dieldrin have ranged from below the CRL of 0.060 ug/l to as high as 0.958 ug/l in a sample collected during fall 1985, as shown in Figure B-121C. The general trend over the last three years of sampling has been for values to decrease, although an order of magnitude variation in concentrations is apparent. Concentrations of the COS have varied less than an order of magnitude in samples from Well 37308 over the last 3 years of sampling (Figure B-121D). Values range from a low of 10.8 ug/l in a sample collected during winter 1987 (second quarter FY87) to a high of 81.8 ug/l in a sample collected in winter 1986. Figure B-121D indicates a generally increasing trend over the last three years but the data set is too limited to assess long term trends. Trichloroethene has never been detected in samples from Well 37308.

Well 37309 is an offpost well located approximately 1,300 ft north of the RMA boundary along Peoria Street. Concentrations of DIMP in samples from Well 37309 have varied from a low of 760 ug/l, reported for a sample collected during summer 1987 (fourth quarter FY87), to a high of 3,990 ug/l reported in a sample collected in August 1978. The general trend since 1978 has been decreasing DIMP concentrations. Since 1981, values have been relatively stable, with reported concentrations in the range of approximately 950 ug/l plus or minus approximately 150 ug/l (Figure B-122A). Reported DBCP concentrations in samples from this well have generally been below the historical CRL of 0.200 ug/l. The reduction of the CRL to 0.130 ug/l resulted in detectable concentrations in the 0.130 to 0.250 ug/l range for samples from Well 37309. Figure B-122B exhibits a generally increasing trend in DBCP concentrations from fall 1985 to summer 1987 although the magnitude of this trend is slight. Because of changing CRLs the long term DBCP trend in this well is difficult to discern. Concentrations of dieldrin exceeding the CRL have never been reported in samples from Well 37309. Observed concentrations of the COS over the last three years have ranged from a low of 30.0 ug/l to a high of 94.8 ug/l (Figure B-122C). The general trend has been increasing concentrations in samples from this well since fall 1984. The long term trends in this well are difficult to assess because of limited COS data. Concentrations of trichloroethene reported in samples from Well 37309 have ranged from a low of 2.54 ug/l in a sample collected during summer 1987 (fourth quarter FY87) to a high of 4.39 ug/l reported in a sample collected during spring 1986 (Figure B-122D). The trichloroethene concentrations in Figure B-122D exhibit a generally decreasing trend.

Well 37313 is located offpost, approximately 400 ft southwest of First Creek along Highway 2. Samples from this well have historically exhibited DIMP concentrations in excess of 10,000 ug/l. The highest observed concentration of DIMP was 11,900 ug/l, reported for a sample collected during January 1979. DIMP concentrations averaged approximately 4,000 ug/l in samples collected during 1986 and 1987 (Figure B-123). Although concentrations have not varied significantly over the last three years, a long term decreasing trend has been evident as described in

Task 36. The compounds DBCP, COS, and trichloroethene have not been detected in samples from Well 37313. Dieldrin was detected at a concentration of 0.086 ug/l in a sample collected during summer 1987 (fourth quarter FY87).

5.1.4.2 Comparison of Upgradient and Downgradient Contamination

A comparison of contaminant concentrations and distributions upgradient and downgradient of the NBCS is included in the Task 36 Report (ESE, 1989a, RIC#89103R01). The following is an excerpt from that discussion with a few additional insights.

A comparison of contaminant distribution maps prepared for DIMP and DCPD for September 1977 (presystem conditions) (Thompson *et al.*, 1985, RIC#86078R01) and for FY87 (Figures B-68A through B-68D and B-70A through B-70D) indicate that distribution patterns for these compounds upgradient of the NBCS have not been significantly altered by the presence and operation of the NBCS. For DBCP, the pattern of distribution seems to have also been relatively unaffected as seen by a comparison of 1979 data (Thompson *et al.*, 1985, RIC#86078R01) and the distributions observed in FY87 (Figures B-69A through B-69D). Although upgradient concentrations of DBCP and DCPD have declined slightly over the last decade, DIMP concentrations appear to have remained relatively unchanged.

Using DIMP, DBCP, and DCPD as indicators, it is suggested that the upgradient distribution of contaminants has not been dramatically altered by the presence of the NBCS. Thus, the present patterns of distribution provide an indicator of onpost contaminant patterns that existed before the installation of the NBCS. Therefore, contaminants presently observed upgradient of the NBCS and east of D Street would generally have been expected to follow historical flow directions and to migrate historically along the Northern pathway (Figure 5.1-1). Contaminants observed upgradient of the NBCS and west of D Street would generally have been expected to migrate historically along the First Creek pathway (Figure 5.1-1). Where the distribution of a contaminant upgradient of the NBCS extends to the east and west of

D Street, contaminants would have been expected to migrate historically along both offpost alluvial pathways. The latter situation is illustrated well by the distribution patterns for DIMP. An evaluation of onpost and offpost contaminant distributions suggests that the organic contaminants near the NBCS generally migrated in this manner.

The spatial distribution of relatively mobile contaminants near the RMA north boundary suggests that much of the present offpost contamination is a result of pre-system migration. An examination of contamination distribution onpost near the NBCS and in the offpost area indicates that the plumes of relatively mobile compounds are discontinuous in the north-south direction across the area of the NBCS. For example, DIMP concentrations exceeding 1,000 ug/l were observed immediately upgradient of the soil-bentonite barrier of the NBCS, but concentrations exceeding 1,000 ug/l downgradient of the system were generally not observed within a half-mile of the system. Instead, DIMP concentrations exceeding 1,000 ug/l were observed more than a half mile downgradient of the NBCS. A similar distribution pattern was observed for DBCP. DBCP concentrations exceeding 5.0 ug/l were noted just upgradient of the soil-bentonite barrier, but downgradient DBCP concentrations exceeding 5.0 ug/l were only noted in samples collected more than one mile downgradient of the NBCS (ESE, 1989a, RIC#89103R01).

It would be expected that the effects of the NBCS in reducing offpost concentrations of individual contaminants differs depending upon the transport characteristics of different compounds. To evaluate the relative effects of the NBCS on contaminants of varying mobility in ground water, several contaminants of different transport characteristics were examined. DIMP and chloroform were chosen as "highly" mobile contaminants because they migrate at rates similar to that of ground water. DBCP and DCPD were chosen as being representative of "moderately" mobile constituents, and dieldrin was chosen as a "low" mobility compound.

Figures B-68A through B-68D, B-69A through B-69D, and B-70A through B-70D in Appendix B show the chemical distribution of DIMP, DECP, and DCPD, respectively, from samples collected in the study area during FY87. Figures B-71A through B-71D show the distributions of dieldrin and Figures B-78A through B-78D show the distributions of chloroform.

The highest DIMP concentrations observed from wells sampled directly upgradient of the system are generally an order of magnitude higher than those obtained from wells sampled along 96th Avenue. Samples obtained from wells within 1,000 ft downgradient of 96th Avenue generally show concentrations less than upgradient well samples but greater than from samples obtained along 96th Avenue. The declines in concentrations noted in well samples collected along 96th Avenue are generally greater east of D Street. DIMP concentrations observed from samples collected from wells over a half-mile from the RMA north boundary were generally similar in magnitude to upgradient concentrations. These higher offpost concentrations were observed in samples from Wells 37373 and 37391, which are located along the First Creek paleochannel and the Northern pathway, respectively.

The highest chloroform concentrations observed in samples from upgradient wells were generally two orders of magnitude higher than concentrations observed from well samples collected downgradient and along 96th Avenue. Chloroform was not detected at concentrations exceeding CRLs in well samples collected along the First Creek pathway. Samples from offpost Well 37389, which is located approximately 600 ft downgradient of 96th Avenue and approximately 800 ft east of Peoria Street, exhibited higher chloroform concentrations in the third and fourth quarter FY87 than those observed from wells sampled along 96th Avenue. However, these concentrations were less than concentrations observed in upgradient well samples. Samples from offpost Wells 37391 and 37392, located more than a half-mile downgradient of the NBCS and along the Northern pathway, exhibited chloroform concentrations near 100 ug/l. These concentrations are less than the highest

concentrations observed from upgradient well samples, but higher than downgradient concentrations observed in samples from wells closer to the NBCS.

The distribution of DCPD concentrations from samples obtained from the monitoring wells in the NBCS are shown in Figures B-70A through B-70D. DCPD concentrations in wells sampled directly upgradient of the NBCS were generally an order of magnitude higher than concentrations from wells sampled downgradient and along 96th Avenue. In fact, only two concentrations of DCPD exceeding CRLs were observed in samples collected from wells along 96th Avenue.

DCPD concentrations exceeding CRLs were observed in samples from offpost wells along the First Creek pathway but not along the Northern pathway. Concentrations of DCPD in samples from wells within 1,000 ft of the NBCS were generally lower than those beyond 1,000 ft from the NBCS. Third and fourth quarter DCPD concentrations observed in samples from offpost Wells 37381, 37309, and 37373 were of similar magnitude as the highest concentrations observed in upgradient wells. These three offpost wells are located more than 1,000 ft downgradient of the NBCS.

The distribution of DBCP in the study area is shown in Figures B-69A through B-69D. The highest DBCP concentrations observed in samples from wells upgradient of the NBCS were generally an order of magnitude greater than the highest concentrations observed in downgradient samples from wells along 96th Avenue. Only three wells sampled along 96th Avenue during FY87 exhibited concentrations of DBCP exceeding CRLs. These downgradient detections corresponded to samples from Wells 24161, 24162, and 23043, and the concentrations observed were less than 1.00 ug/l.

DBCP was generally not observed at concentrations exceeding CRLs in offpost well samples collected along the First Creek pathway. Concentrations of DBCP were observed in third and fourth quarter samples from wells along the Northern pathway. Samples from offpost Wells 37309 and 37389, which are within 1,500 ft of the NBCS,

exhibited concentrations of DBCP below 1.00 ug/l. The highest offpost concentration of DBCP was detected in a sample from Well 37391 which is located a half-mile beyond the NBCS along the Northern Pathway. The concentration observed in samples from this well were greater than 4.00 ug/l, which is similar in magnitude to the highest concentrations observed in samples from wells upgradient of the NBCS.

Dieldrin concentrations observed from well samples collected upgradient of the NBCS were generally of similar magnitude to those observed in well samples collected downgradient and along 96th Avenue. Dieldrin was detected in offpost Wells 37369, 37391, 37392, 37378, 37343 and 37313 above CRLs. Wells 37313, 37343, 37378, and 37391 are located approximately a half-mile downgradient of the NBCS, and data from these wells indicate that dieldrin has migrated along both primary offpost alluvial pathways. Downgradient dieldrin concentrations tended to decrease with increasing distance from the NBCS. This trend differs from the downgradient trends observed for the other four more mobile contaminants considered.

The patterns of contamination distribution downgradient of the NBCS are similar for compounds with similar mobility in ground water. Downgradient DIMP and chloroform concentrations, the most mobile contaminants of the five analytes examined, exhibit a pattern of increasing offpost concentrations with increasing distance from the RMA north boundary. Concentrations of chloroform and DIMP observed in samples collected over a half-mile downgradient from the NBCS were of similar magnitude to the highest concentrations observed in samples obtained upgradient of the system. Offpost concentrations of DIMP and chloroform immediately downgradient of the NBCS were generally an order of magnitude less than upgradient concentrations. This indicates that the NBCS has had a significant impact on reducing offpost concentrations of DIMP and chloroform. However, the persistence of detectable levels of DIMP in samples collected downgradient of the pilot portion of the system may suggest that measurable contaminant transport may be occurring in this area.

Downgradient DBCP concentrations also exhibited a pattern of increasing concentrations with increasing distance from the NBCS. The concentration of DBCP observed in a sample collected over a half-mile downgradient of the NBCS along the Northern pathway was of similar magnitude to the highest concentrations observed in well samples collected upgradient of the system. Offpost DBCP concentrations observed in well samples obtained close to the RMA north boundary were generally an order of magnitude lower than upgradient concentrations. However, detectable levels of DBCP were observed in wells along 96th Avenue and near D Street, which may indicate that some contaminant bypass is occurring in this area. Downgradient DBCP concentrations tended to exhibit a pattern of increasing levels with increasing distance from the NBCS. DIMP and chloroform, which are considered only slightly more mobile than DBCP in ground water, exhibited a similar pattern offpost.

Downgradient DCPD concentrations also exhibited a pattern of increasing concentrations with increasing distance from the NBCS. However, the highest downgradient concentrations were observed closer to the NBCS than those for chloroform, DIMP, and DBCP. This is probably due to higher sorptive properties as indicated by higher estimated Kd values for DCPD as compared to DBCP, chloroform, and DIMP.

Dieldrin concentrations exhibited a completely different distribution pattern than the other four analytes examined. Concentrations immediately upgradient and downgradient of the NBCS generally did not differ greatly from one another, although concentrations exceeding CRLs were not noted downgradient near the North Bog. Downgradient dieldrin concentrations generally decreased with increasing distances from the RMA boundary. This is an indication that historically dieldrin has migrated more slowly in the downgradient area than the other analytes examined. The dieldrin distribution patterns also suggest that the NBCS has not had as pronounced an effect on reducing downgradient dieldrin concentrations as with the other more mobile constituents.

It is indicated from examining contaminant distribution patterns that the NBCS has had a significant affect on the distribution patterns of organic compounds in the offpost area. Although contaminant concentrations are generally an order of magnitude less immediately downgradient of the NBCS versus upgradient, detectable levels of mobile constituents such as DIMP and DBCP still persist along 96th Avenue. This was noted downgradient of the pilot portion of the system and may be an indicator of contaminant bypass in this area.

5.1.5 INFLUENCE OF THE NWBCS

The NWBCS is described in the Introduction, Section 1.1.2. The system has been effective in reducing concentrations of DIMP, a highly mobile contaminant, and DBCP, a moderately mobile contaminant. Both of these contaminants were detected in very low concentrations in a few wells downgradient of the NWBCS, whereas concentrations upgradient were significantly higher. Dieldrin concentrations have not been reduced significantly and continue to persist downgradient of the NWBCS. The highest concentrations exist immediately downgradient of the barrier and concentrations decrease to the northwest. High concentrations immediately downgradient of the system may be due to stagnant water which has not been flushed by the system. Also, due to the relatively low mobility of dieldrin, it is probable that the NWBCS has not been in operation for an appropriate amount of time to cause a significant reduction in dieldrin concentrations. The available information indicates, however, that the carbon adsorption system is removing this contaminant.

Chloroform is also one of the primary contaminants present downgradient. Similar to dieldrin, highest concentrations exist immediately downgradient of the barrier. However, this distribution cannot be the result of low mobility as chloroform is highly mobile. Effluent concentrations examined in 1987 by ESE were discovered to be the same as concentrations observed in downgradient monitoring well samples. Apparently, chloroform has been breaking through the carbon system. Efforts are currently underway to alleviate this problem.

5.2 NATURE AND EXTENT OF DENVER FM CONTAMINATION

Previous studies conducted in the Task 25 area have performed limited investigations of the extent of Denver Fm contamination. The Army collected Denver Fm water quality data from four monitoring wells and seven dewatering wells in the vicinity of the NBCS. These data were collected as part of the Operational Assessment Reports for FYs 84, 85, and 86 (Thompson *et al.*, 1985, RIC#86078R01; PMSO, 1987a, RIC#87320R01). The contaminants evaluated in these studies include: DIMP, DBCP, DCPD, pesticides, organosulfur compounds, chloride, and fluoride. An assessment of Denver Fm contamination in the vicinity of the NWBCS was not performed in conjunction with the Operational Assessment Report for FYs 85 and 86 (PMSO, 1987b, RIC#88054R01). Denver Fm water quality data were collected under Task 4 for the entire RMA (ESE, 1986, RIC#87013R01) and these regional data provide an initial indication of Denver Fm contamination in the Task 25 area, although the density of data points is limited.

Water quality data from a monitoring network incorporating 80 wells have been evaluated to assess the extent of Denver Fm contamination. The network varied slightly from quarter to quarter as new monitoring wells were installed, and therefore not every Denver well was sampled each quarter. The locations of the monitoring wells are illustrated in Figure B-24B. The objectives of this assessment are two-fold, and include:

- Evaluation of the lateral and vertical distribution of contaminants within the Denver Fm hydrostratigraphic zones identified in the Task 25 study area; and
- Identification of areas of interaction between the Denver Fm and the overlying alluvial aquifer, which are resulting in the deterioration of Denver Fm water quality.

5.2.1 DATA PRESENTATION

Contaminant point plots have been constructed for the Denver hydrostratigraphic units of the Denver Fm identified in the Task 25 study area. These point plots illustrate the concentrations and distributions of the primary Denver Fm contaminants

observed in samples collected during FY87. Table 5.2-1 presents a list of target analytes detected in Denver Fm wells by sampling quarter and hydrostratigraphic zone. The extensive list of analytes combined with four Denver Fm hydrostratigraphic zones monitored over four quarters would have resulted in an excessive number of distribution point plots. As a result, distribution point plots were constructed for contaminants, hydrostratigraphic zones, and sampling quarters that exhibited the most numerous detections. These include point plots for DIMP, dieldrin, COS, chloroform, chlorobenzene, benzene, chloride, and fluoride. A summary of the concentrations and distributions of each of the contaminants detected is presented below along with the presentation of the distribution point plots, which are provided in Appendix B. A summary of Denver Fm wells exhibiting contaminant detections tabulated by hydrostratigraphic zone are presented in Table A-5. The data which support the interpretations of Denver Fm water quality are tabulated by well and presented in Appendix A.

5.2.2 CONTAMINANT CONCENTRATIONS AND DISTRIBUTIONS

The concentrations and distributions of each of the contaminants detected in the Task 25 study area during FY87 are summarized below. Discussions are limited to the Task 25 area, which includes the areas upgradient and downgradient of the NBCS and NWBCS. Contaminants detected in Sections 25, 26, and 19 during the Task 44 third quarter FY87 sampling are included on the distribution point plots, but they are not included in the discussions. The individual subsections include a presentation of the data by hydrostratigraphic zone, from zone 4 through zone 1. The data are summarized as the number of detectable concentrations reported during FY87 for each compound in samples from wells completed within a hydrostratigraphic zone. The number of reportable detections by quarter are tabulated in Table 5.2-1. The number of samples collected each quarter are presented in Table A-1. There are no sampled wells completed in zone 1u in the Task 25 study area. Observed third quarter FY87 contamination in Sections 25, 26, and 19, including samples collected from wells completed in the 1u sand, are presented in the Water Remedial Investigation Report (Ebasco, 1989, RIC#89186R01). Comparisons of FY87

Table 5.2-1. Frequency of Occurrence of Target Analytes in Denver Fm Hydrostratigraphic Zones

ANALYTE	FALL 1986				WINTER 1987				SPRING 1987				SUMMER 1987			
	1	10	2	3	4	1	10	2	3	4	1	10	2	3	4	
CL6CP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
ALDRN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
ISODR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
PPDDE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
CLDAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
DLDRN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
ENDRN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
PPDUT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
DCPD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
MIBK	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
DBCP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
DMP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
DMP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
DMS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
BTZ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
OXAT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
DITH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
CPMS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
CPMSO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
CPMSO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
C6H6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
MEC6H5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
ETC6H5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
XYLEN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
CH2CL2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
11DCE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
11DCLE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
T12DCE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
CHCL3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
12DCLE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
111TCE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
OCLA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
TRCLE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
112TCE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
111TCE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
CLC6H5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
CL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
FL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
SO4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
NIT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
CA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
MG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
NA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
K	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
CUOT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
CRUOT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
CUOT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
PHUOT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
ZHUOT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
HGUOT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
ASUOT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Source: ESE, 1988

distributions with historical data were not made due to the limited amount of comparable water quality data from the Denver Fm obtained in previous years.

5.2.2.1 DIMP

Samples from 19 wells completed in hydrostratigraphic zone 4 were analyzed for DIMP during FY87. Samples were not collected from all of these wells every quarter. DIMP was detected at concentrations exceeding the CRL of 10.5 ug/l in four samples collected from two wells. These concentrations ranged in value from 11.5 to 16.7 ug/l and were reported for samples from Wells 37365 and 37321. These offpost wells are located in Sections 14 and 13, respectively, and are probably screened in subcropping sandstones in hydrostratigraphic zone 4. These sandstones are potentially in contact with alluvial materials in this area. However, data defining the areal extent of zone 4 subcrops is fairly limited.

Samples from 20 wells completed in hydrostratigraphic zone 3 were analyzed for DIMP during FY87. DIMP was detected at concentrations exceeding the CRL in eight samples collected from four wells. Detections were reported for samples collected from Wells 23224, 24198, 37371, and 37379. These wells were sampled only during the third and fourth quarters. Concentrations in these samples ranged from 12.6 to 1,480 ug/l. The high concentration was detected in a fourth quarter sample from Well 37371. This well is located in central Section 14 and is probably completed in zone 3 subcropping sandstones underlying the alluvial First Creek Pathway. The presence of these sandstones at the bedrock-alluvial contact increases the potential for aquifer interaction.

Samples from 21 wells completed in hydrostratigraphic zone 2 were analyzed for DIMP during FY87. Figures B-110A through B-110D present distribution point plots for DIMP detected in zone 2. DIMP was detected at concentrations exceeding the CRL in 26 samples collected from 9 wells. Detections were reported for samples from Wells 23177, 23202, 23203, 23204, 24127, 24135, 24184, 24191, and 37323. Concentrations in these samples ranged from 10.5 to 676 ug/l. The highest

concentration was reported in a third quarter sample from Well 24127. This well is located in the northwest quarter of Section 24, upgradient of the NBCS, and in the vicinity of the area of zone 2 subcrop.

There were five wells sampled that are completed in sand layers in hydrostratigraphic zone 1. In addition, there were six wells sampled that appear to be completed in clayshale layers within the hydrostratigraphic zone. There were 11 detections of DIMP in samples collected from six wells during FY87. Five of these wells were completed in clayshale, including 23053, 23106, 23185, 24063, and 24130. Well 24086 is completed in a zone 1 sand. Concentrations in these samples ranged from 11.9 to 5,060 ug/l. The highest concentrations were reported in samples from Well 23185.

5.2.2.2 DBCP

Samples from 19 wells completed in hydrostratigraphic zone 4 were analyzed for DBCP during FY87. There were three reported concentrations for DBCP exceeding the CRL of 0.13 ug/l in samples collected from Wells 37365, 37372, and 37380. Concentrations in these samples ranged from 0.191 to 0.348 ug/l. The highest concentration was detected in a first quarter sample from Well 37365. Samples from subsequent quarters, however, did not exceed the CRL. This well is screened in a subcropping sandstone within zone 4 and therefore water quality in the Denver Fm in this area may be influenced by interaction with alluvial ground water.

Of the 20 wells completed in hydrostratigraphic zone 3, there were no detections of DBCP during FY87.

Samples from 21 wells completed in hydrostratigraphic zone 2 were analyzed for DBCP during FY87. There were 12 detections of DBCP exceeding the CRL in samples from seven wells. Wells exhibiting detections of DBCP include 23203, 23204, 23218, 24127, 24135, 37323, and 37387. Concentrations in these samples ranged from 0.164 to 1.85 ug/l. The highest concentrations were exhibited by samples from Well

23204, which is screened in a subcropping sandstone. Concentrations detected in samples from this well ranged from 0.694 to 1.85 ug/l.

Samples from 11 wells completed in hydrostratigraphic zone 1 were analyzed for DBCP during FY87. Six of these wells appear to be completed in clayshale. There were six detections of DBCP exceeding the CRL, in samples collected from three wells. Concentrations in these samples ranged from 0.609 to 11.6 ug/l. The highest concentrations were exhibited by samples from Well 23106, which is completed in clayshale. The concentrations in these four samples ranged from 4.4 to 11.6 ug/l.

5.2.2.3 DCPD

There were no detections of DCPD in samples from 19 wells completed in hydrostratigraphic zone 4. Of the 20 wells sampled that are completed in hydrostratigraphic zone 3 there was one detection of DCPD exceeding the CRL of 9.31 ug/l in a fourth quarter sample from Well 37371, which is completed in a subcropping sandstone in zone 4. The concentration in this sample was 16.6 ug/l.

Samples from 21 wells completed in hydrostratigraphic zone 2 were analyzed for DCPD during FY87. Seven samples collected from three wells, including 23203, 23204, and 24127, exhibited concentrations exceeding the CRL. All three of these wells are completed in subcropping Denver Fm sandstones. Concentrations in these samples ranged from 27.5 to 169 ug/l. The highest concentration was reported in a third quarter sample from Well 24127.

Samples from 11 wells completed in hydrostratigraphic zone 1 were analyzed for DCPD during FY87. Five samples collected from two wells exhibited concentrations exceeding the CRL. These samples were collected from Wells 23053 and 23106, which are completed in clayshale within the zone. Concentrations ranged from 97.8 to 256 ug/l. The highest concentration was detected in a third quarter sample from Well 23053. This well was sampled only once during FY87.

5.2.2.4 Combined Organosulfur Compounds

There were no detectable concentrations of the organosulfur compounds, CPMS, CPMSO, and CPMSO₂, exceeding the highest CRL of 4.7 ug/l in samples from wells completed in hydrostratigraphic zones 3 or 4.

Samples from 21 wells completed in hydrostratigraphic zone 2 were analyzed for the organosulfur compounds during FY87 (Figures B-113A through B-113D). There were 11 detections for COS exceeding the highest CRL of 4.7 ug/l for the three compounds. These 11 detections were reported in samples from six wells, including 23202, 23203, 23204, 24127, 24135, and 24184. Concentrations in these samples ranged from 6.68 to 141 ug/l. The highest concentrations were reported in a third quarter sample from Well 24127. This well, which is completed in a subcropping Denver Fm sandstone, was only sampled once during FY87.

Samples from 11 wells completed in hydrostratigraphic zone 1 were analyzed for the organosulfur compounds during FY87. Seven detections, exceeding the highest combined CRL of 4.7 ug/l, were reported in samples collected from four wells. One of these wells, 24086, is completed in a zone 1 sandstone. The other three wells, 23053, 23106, and 24130, are all completed in clayshale. Concentrations in these samples ranged from 11.3 to 614 ug/l. The highest concentration was reported in a third quarter sample from Well 23053. This well was sampled only once during FY87.

5.2.2.5 1,4-Oxathiane

Oxathiane was detected in only five Denver Fm wells in the Task 25 study area during FY87. Twenty-one zone 2 wells were analyzed for oxathiane during FY87. Oxathiane was detected at concentrations exceeding the CRL of 1.35 ug/l in four samples collected from two wells completed in hydrostratigraphic zone 2 sandstones; 23203 and 24127. Concentrations in these samples ranged from 1.94 to 2.37 ug/l. There were also seven detections in seven samples collected from Wells 23053, 23106, and 23185. These wells are completed in a clayshale layer in hydrostratigraphic zone 1.

5.2.2.6 1,4-Dithiane

Nineteen zone 4 wells were analyzed for dithiane during FY87. Dithiane was detected in only one sample from a well completed in hydrostratigraphic zone 4. Well 23193 was sampled only during the third quarter of FY87. The concentration of dithiane in this sample was equal to the CRL of 1.68 ug/l. Twenty zone 3 wells were sampled for dithiane during FY87. There were no detections of dithiane in samples collected from hydrostratigraphic zone 3 during FY87.

Samples from 21 wells completed in hydrostratigraphic zone 2 were analyzed for dithiane during FY87. There were seven detections of dithiane in samples from three wells. These were Wells 23203, 23204, and 24127. Concentrations ranged from 1.95 to 6.45 ug/l.

There were 11 zone 1 wells sampled and analyzed for dithiane during FY87. There were five detections in samples from Wells 23106 and 23185. Both of these wells are completed in clayshale layers within the zone. Concentrations in these samples ranged from 3.15 to 34.8 ug/l.

5.2.2.7 Chlorinated Pesticides

There were detectable concentrations of dieldrin, endrin, isodrin, aldrin and p,p'-DDT in samples collected from Denver Fm wells. The distributions of these chlorinated pesticides in Denver Fm wells are summarized below. Chlorinated pesticides were detected in samples collected from wells completed in hydrostratigraphic zones 3, 2, and 1. There were no detections of chlorinated pesticides in samples from wells completed in hydrostratigraphic zone 4.

Dieldrin

There were six reported detections of dieldrin in samples from three of the 20 wells completed in hydrostratigraphic zone 3 during FY87. The samples exhibiting reportable concentrations were collected from Wells 27057, 24120, and 24171. The concentrations reported in these samples ranged from 0.090 to 0.187 ug/l.

Dieldrin was detected at concentrations exceeding the CRL of 0.054 ug/l in samples from 6 of the 21 sampled wells completed in hydrostratigraphic zone 2. The wells included 23189, 23203, 23204, 24127, 24135, and 27049. There were 13 reported detections of dieldrin in samples from these wells during FY87. Concentrations detected in the samples ranged from 0.063 to 1.14 ug/l.

Dieldrin was detected at concentrations exceeding the CRL in samples from 3 of the 11 sampled wells completed in hydrostratigraphic zone 1. These are Wells 23053, 23106, and 24130, all completed in a clayshale layer within the zone. Concentrations in these samples ranged from 0.221 to 2.36 ug/l.

Endrin

There were no detections of endrin in samples collected from Task 25 wells completed in hydrostratigraphic zone 3. Samples from 5 of the 21 monitoring wells completed in hydrostratigraphic zone 2 exhibited detections of endrin exceeding the CRL of 0.060 ug/l. There were six detections in 13 samples collected from Wells 23203, 23204, 23218, 24127, and 24135. The concentrations in these samples ranged from 0.06 to 0.819 ug/l. Samples from three of the 11 monitored wells completed in hydrostratigraphic zone 1 exhibited reportable concentrations of endrin during FY87. These are Wells 23053, 23106, and 24130, all completed in clayshale layers within the hydrostratigraphic zone. There were three detections in five samples collected from these wells. The concentrations in the samples ranged from 0.225 to 1.22 ug/l. The highest concentration reported was observed in a third quarter sample from Well 23053.

Aldrin

There was one reported concentration of aldrin that exceeded the CRL of 0.083 ug/l in a sample from Well 24136. This well is completed in hydrostratigraphic zone 3. The concentration of the sample was 1.03 ug/l. There were no reported detections of aldrin in the Task 25 study area for hydrostratigraphic zones 1 and 2.

Isodrin

There was one detection of isodrin exceeding the CRL of 0.056 ug/l in a sample from Well 23106. This well is completed in a clayshale layer in hydrostratigraphic zone 1. The reported concentration of 0.411 ug/l was in a third quarter sample. This well was sampled all four quarters and was reported below the CRL for the fourth quarter. The samples collected during the first and second quarter sampling periods were reported as elevated detection limits. There were no detectable concentrations of isodrin in hydrostratigraphic zones 2 and 3.

p,p'-DDT

Of 21 zone 2 wells sampled during FY87, there were detectable concentrations of p,p'-DDT in two out of five samples collected from Wells 23204 and 24127. Concentrations in these samples were 0.289 ug/l in a first quarter sample from Well 23204 and greater than 0.066 ug/l in a third quarter sample from Well 24127. There were no detections of p,p'-DDT in samples from hydrostratigraphic zones 1 and 3.

5.2.2.8 Volatile Organohalogenes

The volatile organohalogenes chloroform, trichloroethene, tetrachloroethene, methylene chloride, 1,2-dichloroethane, 1,1-dichloroethane, and t-1,2-dichloroethene were detected in samples collected from Denver Fm wells. The concentrations and distribution of each are summarized below.

Chloroform

Samples from 19 zone 4 wells were analyzed for chloroform during FY87. Samples from three wells completed in hydrostratigraphic zone 4 exhibited detections of chloroform exceeding the CRL of 1.88 ug/l. These samples were collected from Wells 23201, 37321, and 37365. All of the detections were in first quarter samples and the concentrations ranged from 3.46 to 12.4 ug/l. Samples collected during subsequent quarters exhibited concentrations below the CRL. Samples from 3 of the 20 monitoring wells completed in hydrostratigraphic zone 3 exhibited detections of

chloroform exceeding the CRL. These samples were collected from Wells 23209, 24168, and 37318. The four reportable concentrations ranged from 2.41 to 13.1 ug/l.

Samples from 12 of the 21 monitoring wells completed in hydrostratigraphic zone 2 exhibited detections of chloroform exceeding the CRL (Figures B-108A through B-108D). These samples were collected from Wells 23177, 23182, 23202, 23204, 23218, 24127, 24135, 24167, 24184, 27049, 37323, and 37387. There were 26 detections in 34 samples from these wells. Concentrations ranged from 2.03 to 104 ug/l. The highest concentration was reported in the third quarter sample from Well 24127, which is completed in a zone 2 subcropping sandstone.

Samples from 4 of the 11 monitoring wells completed in hydrostratigraphic zone 1 exhibited detections of chloroform exceeding the CRL. These samples were collected from Wells 24089, 23053, 23106, and 24130. Well 24089 is completed in sandstone, while Wells 23053, 23106, and 24130 are all completed in clayshale. There were seven reported detections in seven samples collected from these wells. The concentrations ranged from 26.5 ug/l in a third quarter sample from Well 24089 to 10,900 ug/l in a fourth quarter sample from Well 23106.

Trichloroethene

There were no detected concentrations of TRCLE exceeding the CRL of 2.76 ug/l in samples collected from wells completed in hydrostratigraphic zones 3 and 4.

Samples from 5 of the 21 monitoring wells completed in hydrostratigraphic zone 2 exhibited concentrations exceeding the CRL. The samples were from Wells 23203, 23204, 24127, 24135, and 24197. For the ten reportable values concentrations ranged from 3.86 to 70.1 ug/l. The highest concentrations were detected in samples from Well 23204.

Of samples collected from 11 wells, there were seven detections of TRCLE in samples collected from four wells completed in hydrostratigraphic zone 1. These four wells

include 24124, which is completed in a zone 1 sandstone, as well as 23053, 23106, and 24130, which are completed in clayshale units. Concentrations ranged from 6.67 to 95.4 ug/l. The highest concentrations were consistently detected in samples from Well 23106, where concentrations ranged from 50.1 to 95.4 ug/l.

Tetrachloroethene

There were five detectable concentrations of TCLEE, which exceeded the CRL of 1.1 ug/l, in samples collected from 4 of the 19 monitored wells completed in hydrostratigraphic zone 4.

These wells included 27054, 37365, 37372, and 37388. Concentrations in these samples ranged from 1.24 to 4.60 ug/l.

There were three detections of TCLEE in samples from 3 of the 20 monitoring wells completed in hydrostratigraphic zone 3. The wells included 23219, 37376, and 37379. Concentrations in these samples ranged from 1.33 to 1.38 ug/l.

There were ten detections of TCLEE in samples collected from 8 of the 21 wells completed in hydrostratigraphic zone 2. Sampled wells which exhibited detectable concentrations included: 23203, 23204, 23218, 24127, 24135, 24197, 27049, and 37387. Concentrations in these samples ranged from 1.56 to 12.1 ug/l. The highest concentration was reported in a third quarter sample from Well 24127. This well was only sampled once during FY87.

There were five reported concentrations of TCLEE exceeding the CRL in samples collected from 2 of the 11 wells completed in hydrostratigraphic zone 1. These wells, 23053 and 23106, are completed in clayshale units within zone 1. Concentrations in these samples ranged from 1.58 to 7.65 ug/l.

Methylene Chloride

There were concentrations of methylene chloride exceeding the CRLs of 2.48 and 5.00 ug/l in samples from 2 of the 19 zone 4 monitoring wells, 24175 and 37365. The higher CRL applies to the offpost sample. Both of the detections were reported in first quarter samples and concentrations were 4.25 and 5.33 ug/l, respectively. Samples from subsequent quarterly sampling exhibited concentrations below the CRL.

There was one detection of methylene chloride in a first quarter sample from zone 3, Well 24168. The concentration of methylene chloride in this sample was 4.61 ug/l. There were no detections in samples collected during subsequent quarters.

There was one detection of methylene chloride in a sample from a well completed in a hydrostratigraphic zone 2 sandstone. The concentration in the first quarter sample from Well 24167 was 5.70 ug/l.

There were detections of methylene chloride in two wells completed in zone 2 clayshales sampled during FY87. The three detections in samples from Wells 23053 and 23106 ranged from 11.7 to 58.9 ug/l.

1,2-Dichloroethane

A sample from 1 of the 19 zone 4 monitoring wells exhibited concentrations of 1,2-dichloroethane exceeding the CRL. There were two CRLs for this compound, 0.610 and 1.93 ug/l. The concentration in the first quarter sample from Well 23187 was 0.648 ug/l. There were no detections of this contaminant in samples from wells completed in hydrostratigraphic zone 3.

There were seven detections of 1,2-dichloroethane in samples collected from 3 of the 21 zone 2 monitoring wells. The concentrations in Wells 23203, 23204, and 24127 ranged from 2.24 to 9.18 ug/l.

Of the samples collected from 11 zone 1 wells, two samples from Well 23106 exhibited concentrations of 1,2-dichloroethane that exceeded the CRL. The third and fourth quarter samples from this well exhibited concentrations of 47.8 and 30.0 ug/l, respectively. A reportable concentration of 1,2-dichloroethane was also observed in a fourth quarter sample from Well 24124. The concentration detected in this sample was 10.4 ug/l.

1,1-Dichloroethane

Of the 11 sampled wells completed in hydrostratigraphic zone 1 there were concentrations exceeding the CRL of 1.93 ug/l for 1,1-dichloroethane in samples from two wells, 23053 and 23106. The third quarter sample from Well 23053 exhibited a concentration of 2.11 ug/l. The fourth quarter sample from Well 23106 exhibited a concentration of 2.3 ug/l. There were no detections of this compound in samples from wells completed in hydrostratigraphic zones 2, 3, or 4.

Trans-1,2-dichloroethene

Of the 112 Denver Fm wells analyzed for t-1,2-dichloroethene during FY87, one sample from Well 23106 exhibited concentrations of t-1,2-dichloroethene exceeding the CRL of 1.75 ug/l. This well is completed in a clayshale unit within hydrostratigraphic zone 1. The concentration reported for this sample was 2.28 ug/l. There were no reported concentrations of this compound in samples from zone 2, 3, or 4 wells.

5.2.2.9 Volatile Aromatics

There were numerous detections of the volatile aromatic compounds benzene and chlorobenzene in samples collected from Denver Fm wells during FY87. There were also a small number of detections of toluene, ethylbenzene, and the xylene compounds. The concentrations and distributions of these contaminants are summarized below.

Benzene

Of the 19 zone 4 wells sampled during FY87, there were eight reported concentrations of benzene exceeding the CRLs of 1.34 or 1.92 ug/l in first and third quarter samples collected from 8 wells (B-101A and B-101B). These wells include 23187, 24137, 24175, 27054, 37317, 37372, 37380, and 37388. Concentrations observed in these samples ranged from 3.65 to 10.3 ug/l over the four sampling quarters.

Of the 20 zone 3 wells sampled during FY87, there were 16 reported detections of benzene in samples collected from 13 wells (Figures B-105A through B-105D). These wells include 22027, 23161, 23190, 23192, 23209, 23219, 24136, 24168, 24174, 37318, 37376, 37379, and 37390. Observed concentrations ranged from 2.32 to 24.6 ug/l over the four sampling quarters.

Of the 21 zone 2 wells sampled during FY87, there were nine reported detections of benzene in samples collected from nine wells. Figures B-112A through B-112C present the benzene distributions for the first, third, and fourth quarters. There were no detectable concentrations of benzene for the second quarter sampling. The wells exhibiting detections include 23180, 23181, 23186, 23218, 24127, 24167, 24197, 37323, and 37387. Observed concentrations ranged from 2.14 to 73.8 ug/l over the four sampling quarters. The highest concentration was observed in a third quarter sample from Well 37387.

Of the 11 zone 1 wells sampled during FY87, there were five reported detections of benzene in samples collected from three wells. These wells include 23053, 23106, and 24063. All of these wells are completed in a clayshale layer within the hydrostratigraphic zone. Observed concentrations ranged from 4.06 to 19.6 ug/l during the four sampling quarters.

Chlorobenzene

Thirteen samples collected from 6 of the 19 zone 4 wells sampled during FY87 exhibited concentrations of chlorobenzene exceeding the CRL of 1.36 ug/l. These

wells include 23201, 24175, 37321, 37372, 37380, and 37388. Observed concentrations ranged from 2.07 to 42.4 ug/l during the four sampling quarters.

Twenty samples collected from 13 of the 20 zone 3 wells sampled during FY87 exhibited concentrations of chlorobenzene exceeding the CRL (Figures B-104A through B-104D). These wells include 23200, 23209, 23219, 23224, 24168, 24171, 24174, 24198, 37318, 37376, 37379, and 37390. Observed concentrations ranged from 1.55 to 33.0 ug/l during the four sampling quarters.

Nine samples collected from 6 of the 21 zone 2 wells sampled during FY87 exhibited concentrations of chlorobenzene exceeding the CRL (Figures B-111A through B-111C). There were no second quarter detections of chlorobenzene in samples from zone 2 wells and therefore no distribution plot is presented for this quarter. Samples from Wells 23218, 24167, 24191, 24197, 37323, and 37387 exhibited detections of chlorobenzene. Observed concentrations ranged from 3.23 to 74.7 ug/l. The highest concentration was detected in a third quarter sample from Well 37387.

There were no detections of chlorobenzene in samples from the 11 Task 25 monitoring wells completed in hydrostratigraphic zone 1.

Toluene, Ethylbenzene, and the Xylenes

Of the 19 sampled wells completed in hydrostratigraphic zone 4, a sample from only one well exhibited concentrations of toluene, ethylbenzene, and the xylene compounds. Well 27054 was sampled during the first and third quarters. Toluene (CRL 1.21 ug/l) was detected in both samples at concentrations less than 3 ug/l. Ethylbenzene (CRL 0.62 ug/l) was detected in the first quarter sample at a concentration of 0.93 ug/l. M-xylene (CRL 1.35 ug/l) was detected in the first quarter sample at a concentration of 1.49 ug/l. O- and/or p-xylene (CRL 1.34 ug/l) was detected in the first quarter sample at a concentration of 1.52 ug/l.

There were no detections of these compounds in samples collected from wells completed in hydrostratigraphic zone 3 during FY87.

Of the 21 zone 2 wells sampled during FY87, samples from two wells exhibited concentrations of ethylbenzene exceeding the CRL of 0.620 ug/l. The second quarter sample from Well 23202 exhibited a concentration of 1.10 ug/l. The third quarter sample from Well 37387 exhibited a concentration of 1.32 ug/l. Well 37387 also exhibited a third quarter detection of m-xylene (CRL 1.04 ug/l) at a concentration of 1.37 ug/l and a third quarter detection of o- and/or p-xylene (CRL 1.34 ug/l) at a concentration of 3.60 ug/l.

Of the 11 zone 1 wells sampled during FY87, samples from one well exhibited detectable concentrations of toluene and ethylbenzene. The third quarter sample from Well 23053 exhibited a concentration of 1.46 ug/l of toluene and a concentration of 1.34 ug/l for ethylbenzene.

5.2.2.10 Inorganics

The inorganic analytes arsenic, chloride, and fluoride were detected in samples from Denver Fm wells. The concentrations and distributions of these analytes are summarized below.

These elements often occur naturally in detectable concentrations. Naturally occurring concentrations in samples from Denver Fm wells are summarized for reference in Table 5.2-2.

Arsenic

Of the 19 zone 4 wells sampled during FY87, samples from four wells exhibited concentrations of arsenic exceeding the CRL of 2.50 ug/l. The wells include 22023, 24175, 27058, and 37317. Observed concentrations in four samples ranged from 2.72 to 7.23 ug/l during the four quarters of sampling.

Table 5.2-2. Representative Water Quality from the Denver Fm
(Concentrations in ug/l)

	Denver Aquifer Near Denver * (Robson, 1984)	Denver Aquifer Denver Basin ** (Van der Leeden, 1975)	Denver Aquifer Well Located Upgradient/RMA*** (McConaghy, 1964)
Fluoride	1,600	1,200	1,400
Chloride	3,800	6,000	14,000
Sulfate	13,000	20,000	2,300
Arsenic	--	--	--
Calcium	11,000	--	51,000
Cadmium	--	--	--
Chromium	--	--	--
Copper	--	--	--
Potassium	1,000	--	3,000
Magnesium	400	--	9,200
Sodium	57,000	82,000	36,000
Nitrate	50	30	8,300
Lead	--	--	--
Zinc	--	--	--

* From selected chemical analysis of ground water from the Denver Aquifer near Denver.

** From selected chemical analyses of ground water in the Denver Basin, Colorado.

*** Single Denver FM well located approximately 0.5 mile southeast of RMA, T35 R66W, Section 17.

-- Not analyzed.

Source: ESE, 1988.

Of the 20 zone 3 wells sampled during FY87, samples from 4 wells exhibited concentrations of arsenic exceeding the CRL of 2.50 ug/l. The wells include 23200, 24171, 24174, and 27057. Observed concentrations in six samples ranged from 3.34 to 3.97 ug/l during the four sampling quarters.

Of the 21 zone 2 wells sampled during FY87, a sample from one well exhibited concentrations of arsenic exceeding the CRL. The third quarter sample from Well 23202 exhibited an arsenic concentration of 2.58 ug/l.

Of the eleven zone 1 wells sampled during FY87, samples from four wells exhibited concentrations of arsenic exceeding the CRL. The wells include 23053, 23106, 23185, and 24063.

Observed concentrations in six samples ranged from 3.11 to 9.08 ug/l during the four sampling periods.

Fluoride

Of the 19 zone 4 wells sampled during FY87, samples from 12 wells exhibited concentrations of fluoride exceeding the CRL of 1,000 ug/l. Figures B-102A through B-102C present the distribution of fluoride in hydrostratigraphic zone 4. Observed concentrations in 16 samples ranged from 1,170 to 3,700 ug/l over the four sampling quarters.

Twenty wells sampled and analyzed for fluoride are completed in hydrostratigraphic zone 3. Thirteen of these wells exhibited concentrations of fluoride exceeding the CRL. Figures B-106A through B-106D illustrate the distribution of fluoride in hydrostratigraphic zone 3. Observed concentrations in 23 samples ranged from 1,070 to 3,990 ug/l during FY87.

Of the 21 wells completed within hydrostratigraphic zone 2 and sampled during FY87, there were 16 wells for which samples exhibited concentrations of fluoride exceeding

the CRL of 1,000 ug/l. Figures B-114A through B-114C present the distribution of fluoride in zone 2. As the figures illustrate, the reported concentrations of fluoride were most widespread during the third quarter sampling event. Observed concentrations in 27 samples range from 1,170 to 4,820 ug/l during the four sampling periods.

Of the 11 zone 1 wells sampled, ten exhibited concentrations of fluoride exceeding the CRL. Figures B-117A through B-117D illustrate the distribution of fluoride in hydrostratigraphic zone 1. The six wells completed in clayshales within zone 1 are not included in the distribution point plots. Data for these Wells, 23053, 23106, 23185, 24063, 24109, and 24130, are tabulated in Appendix A. Observed concentrations in 24 samples ranged from 1,080 to 7,500 ug/l during the four sampling periods.

Chloride

Samples from all 19 sampled wells completed in hydrostratigraphic zone 4 exhibited concentrations of chloride. Figures B-103A through B-103D illustrate the distribution of chloride in zone 4. The distribution point plots indicate that the highest concentrations of chloride are detected in samples from wells located in the western half of Section 23 and eastern half of Section 22. Observed concentrations in 44 samples ranged from 9,280 to 643,000 ug/l during FY87.

Samples from all 20 sampled wells completed in hydrostratigraphic zone 3 exhibited concentrations of chloride. Figures B-107A through B-107D illustrate the distribution of chloride in zone 3. The distribution point plots indicate that the highest concentrations of chloride are generally detected in wells located in the southwest quadrant of Section 23 and the southeastern quadrant of Section 22. Observed concentrations in 53 samples ranged from 14,800 to 467,000 ug/l during the four sampling quarters.

Samples from all 21 monitored wells completed in hydrostratigraphic zone 2 exhibited concentrations of chloride. Figures B-115A through B-115D illustrate the distribution

of chloride in zone 2. The distribution point plots generally indicate relatively high concentrations in samples from wells located in the eastern half of Section 23 and in the vicinity of the NBCS. Observed concentrations in 56 samples ranged from 13,900 to 670,000 ug/l during the four periods of sampling.

Samples from all 11 monitored wells completed in hydrostratigraphic zone 1 exhibited concentrations of chloride. Figures B-118A through B-118D illustrate the distribution of chloride in zone 1. The six zone 1 wells completed in clayshales are not included on the distribution point plots. The highest Denver Fm concentrations of chloride were reported for samples from wells completed in hydrostratigraphic zone 1 clayshales. Data for these wells are tabulated in Appendix A. Observed concentrations in 30 samples ranged from 29,100 to 4,750,000 ug/l during the four sampling quarters.

5.2.3 CONTAMINATION TRENDS

In general, the contaminants with the widest distribution in the Denver Fm are benzene, chlorobenzene, and chloroform. There are relatively few detections of the remainder of the analytes. Some of the analytes, however, exhibit a greater number of detections in samples from wells in a particular hydrostratigraphic zone. For example, DIMP, dieldrin, and the COS are common contaminants in samples from zone 2 but are observed only infrequently in other zones. Consequently, distribution point plots are provided that illustrate the distribution of these contaminants in this specific hydrostratigraphic zone.

Table 5.2-1 presents a tabulation of the number of detections for each hydrostratigraphic zone by quarter. Table 5.2-1 and the distribution point plots provided in Appendix B indicate that samples from wells completed in zone 2 exhibit a greater number of detections of DIMP, dieldrin, COS, and chloroform than the other shallow Denver Fm zones in the Task 25 study area. The primary reason for this is that the subcrop pattern for zone 2 (Figure B-12) coincides with the primary alluvial transport pathways in eastern Sections 23, western Section 24, and western

Section 13. The greatest concentration of wells completed in zone 2 is in the northeastern quarter of Section 23 and the northwestern quarter of Section 24, in the vicinity of the NBCS. Samples from these wells exhibit the majority of the contamination in zone 2.

The principal contaminants in samples from wells completed in hydrostratigraphic zone 1 are DIMP, chloroform, chlorobenzene, and the chlorinated pesticides. Most of the contamination is detected in samples from wells located in Section 26, which is outside the Task 25 study area. Within the Task 25 study area samples from zone 1 exhibit little contamination. A notable exception to this are the wells completed in zone 1 clayshales. This category includes Wells 23053, 23106, 23185, 24109, 24063, and 24130. Wells 23053 and 23106 are located along the eastern boundary of Section 23. Well 23185 is located in the southwestern quarter of Section 23, beneath an area of unsaturated alluvium. Well 24130 is located approximately 500 ft south of the NBCS in the northwestern quarter of Section 24. Well 24109 is located east of the NBCS beneath an area of unsaturated alluvium in the northeastern quarter of Section 24. Well 24063 is located in central Section 24. Samples from most of these wells exhibit elevated concentrations of DIMP. Samples from Wells 23053, 23106, and 23185 obtained during FY87 exhibited concentrations of DIMP in excess of 1,500 ug/l. Samples from some of these wells also contain detectable concentrations of dieldrin, endrin, dithiane, oxathiane, DBCP, DCPD, COS, chloroform, benzene, TRCLE, and TCLEE, but generally at relatively low concentrations. These wells are completed in subcropping clayshales that occur between zones 1 and 2. The clayshales are generally described on the lithologic logs as massive to slightly fractured. Fractures, if present, are generally tight, with little apparent void space. Although classified as zone 1 wells, their contamination pattern may indicate that they fit more readily into zone 2.

Samples from wells completed in hydrostratigraphic zone 3 generally exhibit relatively low concentrations of benzene, chlorobenzene, and chloroform. There are a limited number of detectable DIMP concentrations reported in samples from zone 3, but

samples from Well 37371 exhibited concentrations of DIMP in excess of 1,000 ug/l. This well is completed in a subcropping sand unit underlying the First Creek alluvial transport pathway.

Samples from wells completed in hydrostratigraphic zone 4 generally exhibit few detections of organic contaminants, with a few notable exceptions. Most of the subcrop for zone 4 is located offpost. Samples collected from a few wells completed in zone 4, north of the RMA boundary, exhibited concentrations of benzene, chlorobenzene, chloroform, DIMP, and DBCP. There may be vertical migration of contaminants from the alluvial aquifer in this area. For DBCP and chloroform, however, this is unlikely. These contaminants are presently detected in alluvial ground water offpost only in the Northern transport pathway, along the eastern boundary of Section 13. DBCP and chloroform concentrations may represent residual contamination from sporadic alluvial contamination in this area, or they may be introduced into zone 4 ground water upgradient of the subcrop area, in the vicinity of the NBCS. However, as has been previously observed, the estimated travel times in the Denver Fm are relatively long and for this reason contaminant transport strictly in the Denver Fm is probably not a dominant transport pathway over long distances.

One method of evaluating the degree of interaction between the hydrostratigraphic zones is to assess the water quality of samples collected from cluster well sites. Table 5.2-3 presents a tabulation of fluoride and chloride data for Denver Fm cluster wells located in the Task 25 study area.

Table 5.2-3 indicates that the concentrations of fluoride and chloride reported in samples from different hydrostratigraphic zones generally show good correlation. A few cluster well sites from Section 26 are included for comparison. This probably indicates a certain degree of communication between the hydrostratigraphic zone in these areas. There are several cluster sites, however, that do not exhibit similar values between two or more of the sampled wells. These include the Cluster Wells 26066/26067, 26071/26072, 27057/27058, 24135/24136/24137, and

Table 5.2-3. Fluoride and Chloride Concentrations for Denver Aquifer Cluster Well Sites (Units in ug/l)

Well	Zone	Fluoride	Chloride
26066	1	3,530	3,200,000
26067	2	<1,000	166,000
26071	1	1,370	519,000
26072	2	<1,000	108,000
27057	3	<1,000	40,000 - 48,500
27058	4	1,580	391,000
22027	3	1,900	346,000
22028	4	1,740	643,000
23221	1	<1,000	57,700
23222	2	<1,000	489,000
23189	2	<1,000 - 1,220	67,000 - 90,000
23190	3	1,310 - 1,360	74,300 - 93,100
23185	1SH	<1,000 - 3,410	534,000 - 1,480,000
23186	2	<1,000 - 1,550	220,000 - 233,000
23187	4	1,380 - 1,830	302,000
23182	2	<1,000 - 3,100	481,000 - 670,000
23183	4	<1,000 - 1,300	361,000 - 483,000
23192	3	<1,000 - 1,360	288,000 - 340,000
23193	4	1,830	442,000
23180	2	<1,000	73,300
23181	2	<1,000	50,200 - 63,800
24197	2	<1,000	13,900
24198	3	3,990	16,900
24135	2	2,150 - 2,860	124,000 - 134,000
24136	3	<1,000	39,100 - 40,500
24137	4	<1,000	33,800 - 34,500
37379	3	3,000	418,000
37380	4	2,100	412,000
37387	2	3,220 - 4,820	303,000 - 287,000
37388	4	2,650	403,000

Source: ESE, 1988.

23185/23186/23187. In each case, the chloride and fluoride values in samples from the upper units are much higher, usually by an order of magnitude, than those in the lower ones. An evaluation of the organic contaminant data indicates that the shallower zone in these areas is much more contaminated than the deeper zone (Table 5.2-4). This indicates restricted vertical communication between the hydrostratigraphic zones in the study area.

5.3 DENVER FM AND ALLUVIAL AQUIFER INTERACTION

The relationship between the Denver Fm and alluvial aquifer is generally one of downward vertical gradient, as noted in Section 4.2.6. Denver Fm wells that exhibit relatively high concentrations of common alluvial contaminants, such as DIMP, are usually completed in subcropping sand layers. These wells are commonly screened in bedrock, underlying areas of highly contaminated alluvial ground water. Examples of this are the zone 2 wells near the NBCS, zone 1 wells screened in the Denver Fm underlying the Section 26 Northeastern Pathway, and the zone 3 wells screened in bedrock underlying the First Creek Pathway. The one notable exception to this is Well 23185, which is completed in a zone 1 clayshale underlying unsaturated alluvium in the southwest quadrant of Section 23. Samples collected from this well exhibit relatively high concentrations of DIMP that are apparently unrelated to any alluvial contamination.

Generally, the contaminants with the widest distribution in the Denver Fm, benzene and chlorobenzene, are not the contaminants that exhibit high concentrations or widespread distribution in alluvial aquifer samples. These contaminants may be introduced to the Denver Fm upgradient of the Task 25 study area. However, estimated travel times in the Denver Fm are relatively long and therefore this is probably not a dominant transport pathway.

An assessment of water quality in single wells that are completed in both the alluvium and Denver Fm indicates that samples from these wells exhibit concentrations of

Table 5.2-4. Selected Organic Contamination in Task 25 Cluster Wells
(concentration in ug/l)

Well Number	Zone	DIMP	Benzene	Chlorobenzene	Chloroform
26066	1	116	4.82	8.62	BCRL
26067	2	BCRL*	BCRL	BCRL	BCRL
26071	1	5230	BCRL	1.74	5.18
26072	2	BCRL	BCRL	BCRL	BCRL
27057	3	BCRL	BCRL	BCRL	BCRL
27058	4	BCRL	BCRL		
22027	3	BCRL	>9.04	BCRL	BCRL
22028	4	BCRL	BCRL	BCRL	
23221	1	BCRL	BCRL	BCRL	BCRL
23222	2	BCRL	BCRL	BCRL	BCRL
23189	2	BCRL	BCRL	BCRL	BCRL
23190	3	BCRL	3.58-24.6	BCRL	BCRL
23185	(1SH)	4,240-5,060	BCRL	BCRL	BCRL
23186	2	BCRL	<1.34-4.36	BCRL	BCRL
23187	4	BCRL	<1.34-5.55		BCRL
23182	2	BCRL	BCRL	BCRL	<1.4-3.5
23183	4	BCRL	BCRL	BCRL	BCRL
23192	3	BCRL	3.94-14.6	BCRL	BCRL
23193	4	BCRL	BCRL	BCRL	BCRL
23180	2	BCRL	2.14	BCRL	BCRL
23181	2	BCRL	1.78-<1.92	BCRL	BCRL
24197	2	BCRL	4.86	47.6	BCRL
24198	3	15.4	BCRL	1.55	BCRL
24135	2	91.2-152	BCRL	BCRL	12.1-22.0
24136	3	BCRL	<1.92-4.26	BCRL	BCRL
24137	4	BCRL	<1.92-5.93		
37379	3	47.1-53.7	5.76	<1.36-17.8	BCRL
37380	4	BCRL	<1.92-3.65	<1.36-15.4	BCRL
37387	2	BCRL	73.8	<1.36-74.7	<1.88-8.62
37388	4	BCRL	10.1	2.07-32.8	BCRL

* BCRL = Below Certified Reporting Limit.
Source: ESE, 1988

common alluvial contaminants and may therefore be more representative of alluvial water quality.

5.4 FIELD QA/QC

Field Quality Assurance/Quality Control (QA/QC) procedures were used to provide documentation of the limits of precision and accuracy of all analytical systems generating data and to provide mechanisms for documentation of the validity of all reported data. Field QC procedures were consistent with EPA and USATHAMA approved methodologies. A summary of these procedures for all trip blanks, rinseate blanks, field blanks, and duplicate samples are presented in Table 5.4-1. The field quality data is presented in Appendix A.5.

Table 5.4-1. Field QA/QC Procedures

Bulk Sample Type	Analytical Method *	Required Frequency	Preparation
Volatile Trip Blank	W8, Y8, TT8, SCS	1 paint can with 3 volatile septum vials each week, each week samples for GC analysis are collected.	Transport filled blank volatile septum vials to field, open paint can and return to laboratory with samples
Rinseate Blank	S8, U8, T8, W8, Y8, X8, K8, R8, Q8	1 suite per week, each week samples are submitted	Decontaminate bailer used to collect samples. Pour deionized water into cleaned bailer, then transfer to sample bottles. Perform while onsite. Not applicable if dedicated bailer is used.
Field Blank	S8, U8, T8, W8, Y8, X8, K8, R8, Q8	1 suite per week, each week samples are submitted	Pour organic free deionized water directly into sample bottles. Perform while onsite.
Duplicates	S8, U8, T8, W8, Y8, X8, K8, R8, Q8	1 suite per week, each week samples are submitted	Collect 2 suites of sample bottles while onsite.

* See Table 2.2-2.

Source: ESE. 1988.

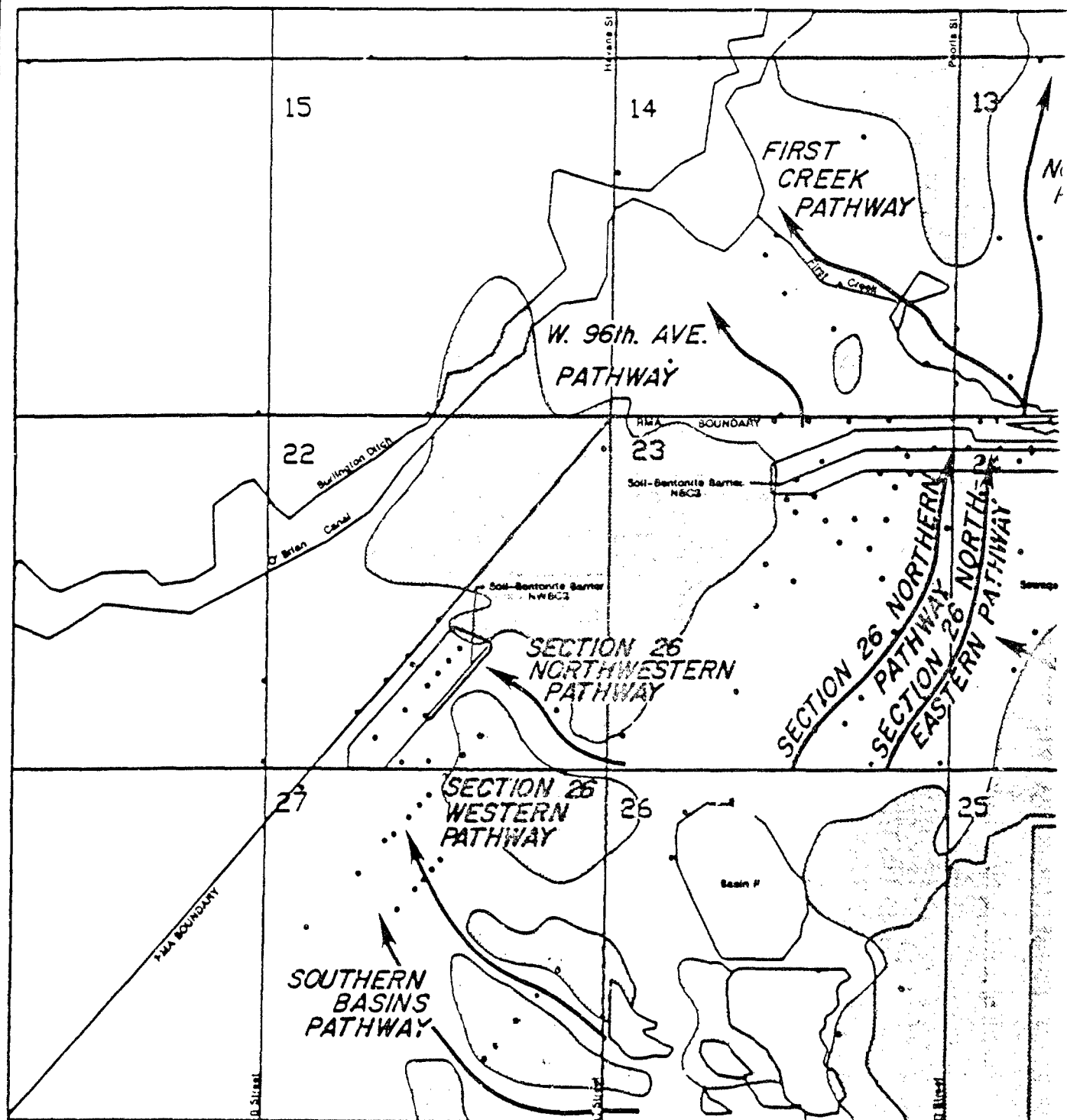
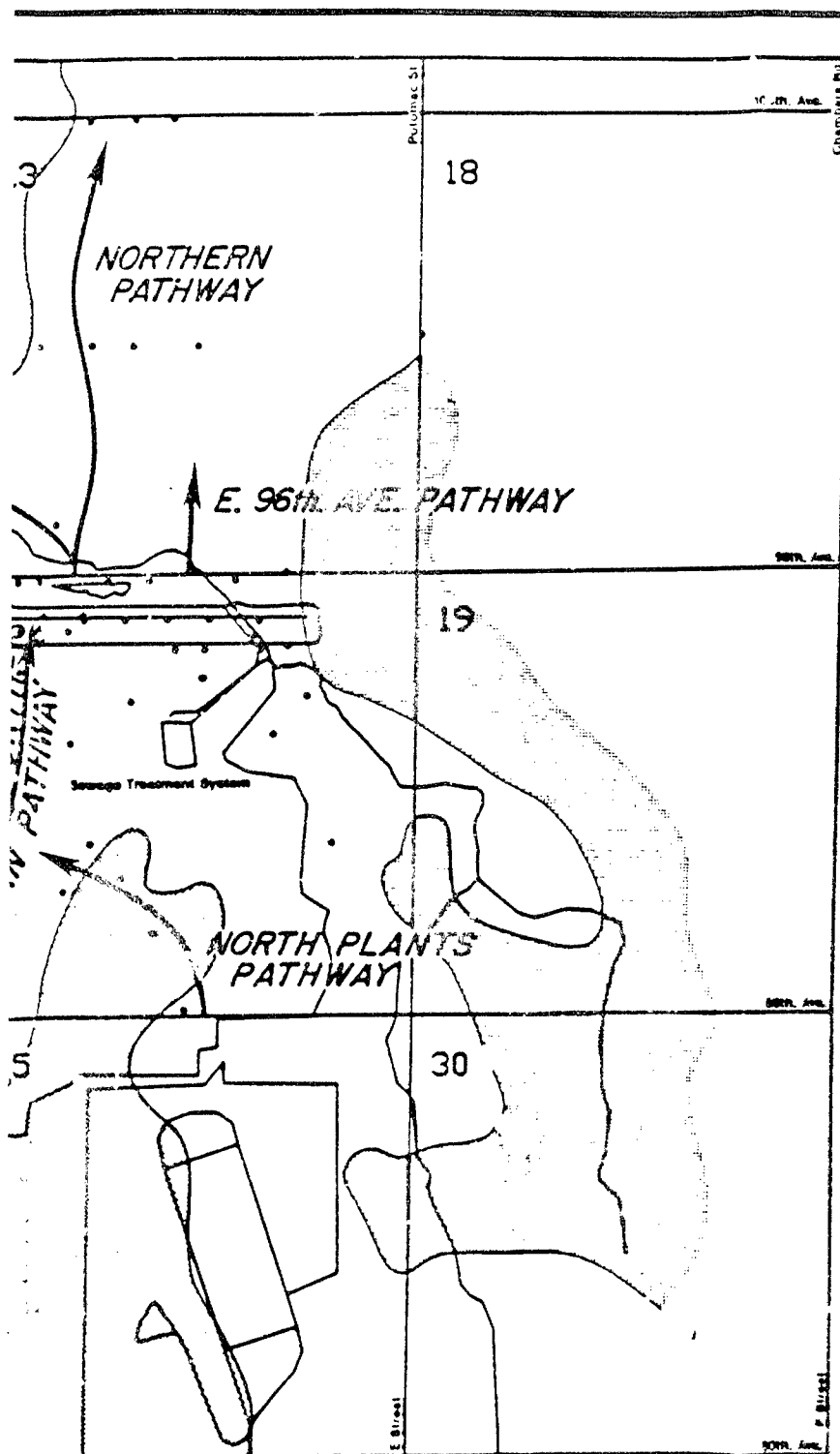


Figure 5.1-1

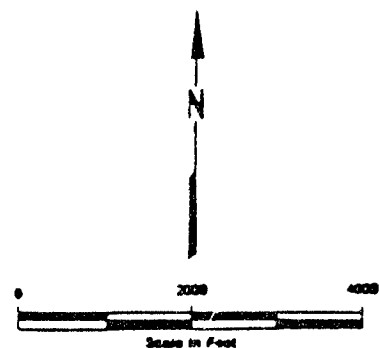
GENERALIZED ALLUVIAL CONTAMINANT TRANSPORT PATHWAYS

SOURCE: ESE, 1988



EXPLANATION

- ALLUVIAL MONITORING WELL
- UNSATURATED ALLUVIUM
- ⚡ CONTAMINANT TRANSPORT PATHWAY
- NWBCS NORTHWEST BOUNDARY CONTAINMENT SYSTEM
- NBCS NORTH BOUNDARY CONTAINMENT SYSTEM



Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland

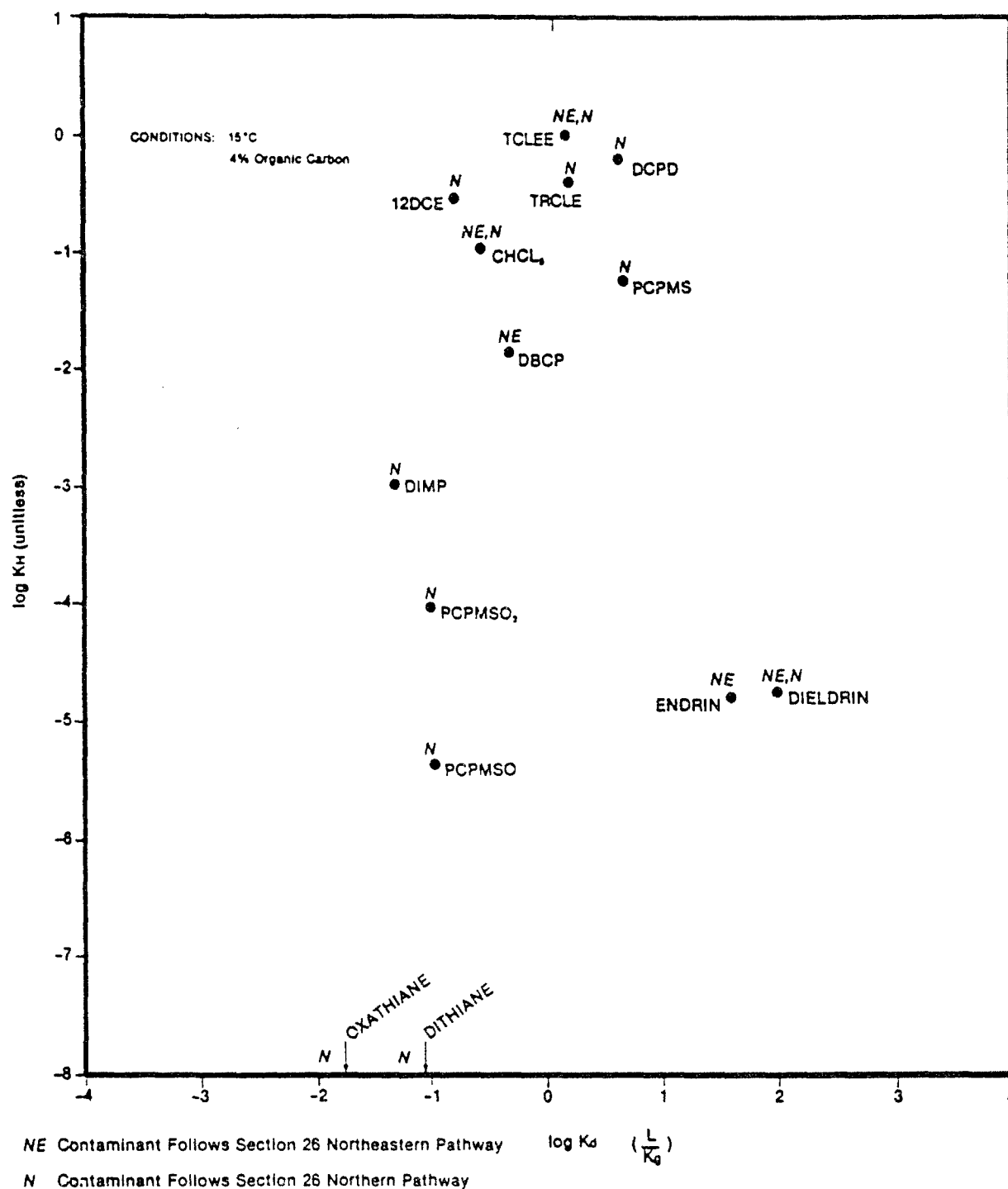


Figure 5.1-2

CONTAMINANT SORPTION AND
VOLATILITY

SOURCE: ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

6.0 CONCLUSIONS

The data collected and evaluated under Task 25 substantiate a complex interpretation of geology, hydrogeology, and contaminant distribution in both the alluvium and Denver Fm. These various components have been evaluated and are described and interpreted in Sections 3.0, 4.0, and 5.0, respectively. This section of the report presents a brief summary and the resulting conclusions regarding geology, hydrogeology, and contaminant distribution and their interrelationships within the Task 25 study area.

Geology

The geology of the heterogeneous surficial deposits at RMA is complex and includes a number of Quaternary alluvial/fluvial and eolian deposits. The evaluations presented in this report are based upon interpretations made by ESE and are consistent with the interpretation presented by MKE (1988). The surficial deposits of primary interest in the Task 25 study area include the relatively coarse-grained alluvial sands and gravels of the Slocum, Louviers, Broadway, and Piney Creek. These sediments comprise the valley-fill material that is in contact with bedrock in the study area and is the primary conduit for ground-water flow in the alluvial aquifer.

The bedrock surface in the study area slopes gradually to the north and is incised by numerous major and minor paleochannels. The coarsest surficial sediments are contained in the paleochannels and represent the primary pathways in the study area for alluvial ground-water and contaminant flow to the north and northwest.

The Denver Fm geology is a complex system of interbedded sandstones and siltstones contained in a dominant matrix of claystones and siltstones. The depositional relationship of these sediments can be interpreted using a meandering fluvial system model. This model includes the relatively coarse-grained sediments of accreting point-bars, which represent the fluvial channel, as well as the coarsening

upward sequences of the crevasse-splay and flood basin deposits. Flood basin deposits are abandoned stream channel and backswamp deposits that are associated with the formation of carbonaceous or lignitic intervals.

The cross-sectional view of the Denver Fm sediments can be described as lenticular sandstone bodies encased in siltstones and claystones. These sandstone lenses have been correlated into generalized hydrostratigraphic zones based upon lithology and depth in the aquifer. In some portions of the study area, these zones are separated by up to 30 ft of clayshale, while in other areas some of the hydrostratigraphic zones appear to be in contact and act as one unit. The division of the Denver Fm into hydrostratigraphic zones appears to be a valid interpretation based on the potentiometric surface and contaminant distribution in each of these zones.

Although the number and density of Denver Fm monitoring wells is not as great as that of alluvial wells, the identification of the hydrostratigraphic zone that each of the wells screen has permitted a more simplified, straight-forward interpretation of water levels and contaminant distribution in the Denver Fm.

A nomenclature scheme based on the presence of a lignite marker bed (LA) was used to name the hydrostratigraphic zones. The zone immediately below LA was named 1u. Zone 1u is underlain by zones 1, 2, 3, and 4. This sequence represents the Denver hydrostratigraphic zones that subcrop in the Task 25 study area.

Evaluations of lithologic logs indicate that the sandstones within these zones are similar in character and description. Maps were constructed of the base of the sandstone portion of each zone, as well as the net thickness of sandstone within each zone. These maps illustrate the channel morphology of the Denver Fm and indicate the areas of thickest extent of sandstone within each zone. The sandstone units exhibit the highest K values within each zone and therefore represent the most likely avenues of contaminant transport within the Denver Fm.

Hydrogeology

The hydrogeology of the alluvial aquifer is complicated by the heterogeneous nature of the sediments encountered and by the effects of the NBCS and NWBCS. The alluvial aquifer is generally classified as unconfined, heterogeneous, and transversely isotropic. In areas where the alluvium is in contact with poorly cemented, subcropping sandstone and siltstone lenses, as well as fractured claystones in the Denver Fm, permeable zones of the two units are physically connected facilitating flow between them. The primary avenues of recharge to the alluvial aquifer are through direct precipitation, recharge from surface water bodies, recharge from the NBCS and NWBCS, and general ground-water flow from areas to the south of the study area.

The water table configuration as presented on quarterly water table maps are similar to those of previous studies (Thompson *et al.*, 1985, RIC#86078R01; PMSO, 1987a, RIC#87320R01 and 1987b, RIC#88054R01). Water table gradients in Sections 23 and 24, upgradient of the NBCS, range from 0.001 ft/ft to 0.03 ft/ft, while gradients in Sections 22 and 27, upgradient of the NWBCS, vary between 0.02 and 0.03 ft/ft. There appears to be less than 2.5 ft of seasonal fluctuation in water levels, from the wettest to the driest quarters. Many of the wells that exhibit seasonal fluctuations in water levels appear to be affected by ground-water recharge from First Creek.

Saturated thicknesses vary with the topography and may be as much as 30-ft thick in the Task 25 study area. Evaluation of previous pumping tests, performed in the vicinity of the NBCS, indicate K values vary between 887 and 7,500 gpd/ft², while T varies between 6,210 and 79,000 gpd/ft. Two previously performed pumping tests, in the vicinity of the NWBCS, indicate K values of 8,557 and 17,690 gpd/ft² and T values of 210,000 and 405,000 gpd/ft. A characterization of the saturated alluvium based on the pumping test data is presented as a T map of the study area. This map confirms previously predicted (Thompson *et al.* 1985, RIC#86078R01; PMSO, 1987a, RIC#87320R01 and 1987b, RIC#88054R01) areas of relatively high T trending northeast across Sections 23 and 24 toward the NBCS, and areas of relatively high T

immediately downgradient of the NWBCS. Estimated Darcian velocities vary between 1.5 and 10 ft/day.

The Denver Fm water-bearing sandstone units represent fluvial meander belts and flood basin type deposits that grade laterally and vertically into finer-grained material. Lateral and vertical changes in depositional environments cause the sandstone units to differ in their capacity to store, transmit, and yield water. Analyses of 12 slug tests performed by ESE, 23 previously conducted slug tests, and 2 previously conducted pumping tests indicate that generally, the Denver Fm sandstones exhibit a K three orders of magnitude less than the coarsest alluvial sediments. Values of T for zone 2 range from 0.160 to 66.5 gpd/ft and K values range from 0.041 to 4.9 gpd/ft². T values in zone 3 range from 3.0 to 160 gpd/ft, while K values range from 0.30 to 8.9 gpd/ft², with a mean value of 3.3 gpd/ft². The T values for zone 4 range from 0.14 to 74.8 gpd/ft, while K values range from 0.01 to 2.7 gpd/ft².

The potentiometric surface maps for hydrostratigraphic zones 1u through 4 indicate a general ground-water flow direction to the north and northwest, although it may vary locally. Calculated hydraulic gradients vary between 0.003 and 0.01 ft/ft.

The direction of vertical ground-water flow is generally downward from the alluvial to the Denver Fm, although a few isolated cluster sites south of the study area exhibit upward gradients from the Denver to the alluvium. Observed vertical gradients between the two aquifers ranged from 0.07 to 0.12 ft/ft. The direction of vertical ground-water flow also appears to be downward within the Denver Fm. Downward vertical gradients vary between 0.02 ft/ft and 0.23 ft/ft between the various zones.

Ground-Water Contamination

Ground-water samples were collected from wells in the Task 25 monitoring network during the four quarters of FY87. The most frequently detected alluvial

contaminants were: DIMP, DBCP, organosulfur compounds, 1,4-oxathiane, 1,4-dithiane, dieldrin, endrin, chloroform, trichloroethene, tetrachloroethene, 1,2-dichloroethane, arsenic, chloride, and fluoride. The distributions of these contaminants are presented in contoured plume maps. The remainder of the analytes were detected sporadically in the alluvial aquifer and the distributions for these contaminants are presented as point plots.

The distributions of compounds in the previous two years assessed in other reports (PMSO, 1987a, RIC#87320R01 and 1987b, RIC#88054R01), including DIMP, DCPD, DBCP, combined organosulfurs, chloride, and fluoride, exhibit a similar pattern for FY87, despite differences in the monitoring networks for the various studies. Earlier investigations (Spaine *et al.*, 1984, RIC#85133R04; Thompson *et al.*, 1985, RIC#86078R01; MKE unpublished data, 1985) display a few variations, some of which can be attributed to differences in the monitoring networks.

Alluvial contaminant distribution patterns appear to follow several transport pathways in the study area. Most of these pathways were described by previous studies, although a few of them were delineated by the present monitoring network, including newly installed wells offpost. These pathways represent zones of high T alluvial sediments. The distributions of contaminants are not limited to these transport pathways, but the highest concentrations are generally detected in samples from wells located along these trends.

Alluvial aquifer contamination pathways delineated by the Task 25 monitoring network include a division between north and northeast pathways through Sections 23 and 24 (Section 26 Northern and Northeastern Pathways); a northwest trending pathway from the vicinity of the North Plants through Section 24 (North Plants Pathway); a northern trending pathway offpost along the eastern boundary of Section 13 (Northern Offpost Pathway); the First Creek Pathway Offpost; and several pathways upgradient of the NWBCS (Section 26 Northwestern Pathway, Section 26 Western Pathway, and Southern Basins Pathway).

The fourth quarter sampling of newly installed wells immediately downgradient of the soil-bentonite barrier at the NBCS indicated the potential for contaminants to be held upgradient of the recharge wells by stagnant water. Samples from the monitoring wells at the boundary of RMA exhibited generally lower levels of contamination than samples from wells upgradient of the recharge wells.

Contaminant concentrations assessed in a group of offpost wells over time indicate that DIMP and DBCP concentrations in the offpost area downgradient of the NBCS have declined since 1978. The construction of the NBCS pilot system in 1978 and the subsequent expansion of the system to the east and west in 1981 would be expected to interrupt the movement of contaminants through the alluvial aquifer across the RMA boundary. However, even though the dominant contaminant pathways to the offpost portion of the alluvial aquifer have been severed, some residual contamination is likely to remain in the saturated sediments downgradient of the boundary system. The length of time required to detect significant decreases in contaminant concentrations downgradient of the boundary system after it has become operational is dependent upon the characteristics of the individual contaminant, the travel time of ground water in the aquifer, and the highly variable characteristics of the soils and sediments in the area. Due to the fact that local alluvial ground-water flow is disrupted by the presence of the NBCS (as well as the NWBCS), contaminant leaching times are very much dependent upon the quantity of water injected downgradient of the system. The most rapid decrease in contaminant concentrations would be expected for more relatively mobile contaminants such as DIMP.

An evaluation of contaminant distributions in the Denver Fm was performed to assess the lateral and vertical distribution of contaminants within and between the various hydrostratigraphic zones. The most commonly encountered contaminants in the Denver Fm include: benzene, chlorobenzene, chloroform, DIMP, COS, and dieldrin. There are also sporadic detections of many of the other target analytes.

The highest concentrations encountered in samples from the Denver Fm appear to be in samples from wells that are completed in bedrock immediately underlying one of the primary alluvial pathways. These wells are often completed in subcropping sandstones that are in contact with the alluvium. It does not appear from the data available that these higher concentrations can be traced upgradient in the Denver Fm. The subcrop for hydrostratigraphic zone 2 is coincident with the areas of highly contaminated alluvial ground water in Sections 23 and 24, and therefore appears to be the most highly contaminated of the Denver Fm zones.

The downward vertical gradient, between the hydrostratigraphic zones, has resulted in relatively low level contamination migrating downward within the Denver Fm. Samples from cluster wells indicate low level concentrations of benzene, chloroform, and chlorobenzene in wells upgradient of the area of subcrop for zones 3 and 4. The highest levels of organic and inorganic contaminants in the Denver Fm appear to be contained in shale samples between zones 1 and 2. The concentrations of these contaminants, including DIMP and chloride, are an order of magnitude higher than those detected in samples from wells in underlying zones. Shales will tend to retain contaminants due to the relatively greater surface area of the fine grained sediments and generally high organic carbon content. The vertical travel times are dependent upon the degree of fracturing in the shale layers. For contaminants in unfractured shales, the vertical travel times may be very long relative to contaminants migrating through sandstone layers.

It appears that interaction between the alluvial and Denver Fm is generally one of downward vertical gradients, although these gradients appear to be relatively small and travel times large. The downward migration of alluvial contaminants appear to be limited to areas of subcropping sandstones and siltstones in the Denver Fm. Although the number of Denver Fm wells is limited, the data collected do not appear to indicate a substantial downward transport of high concentrations of contaminants within the Denver Fm.

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8.0 ACRONYMS AND ABBREVIATIONS

Army	Department of the Army
As	A sand zone - channel
Au	A sand zone - upper
Am	A sand zone - middle
A1	A sand zone - lower
ac-ft	acre-feet
ac-ft/mo	acre-feet per month
ac-ft/yr	acre-feet per year
ASTM	American Society for Testing and Materials
CDH	Colorado Department of Health
CF&I	Colorado Fuel and Iron
cfs	cubic feet per second
cm/sec	centimeters per second
CO	carbon monoxide
COE	U.S. Army Corps of Engineers
COR	Contracting Officer's Representative
COS	combined organosulfur compounds
CPMS	chlorophenylmethyl sulfide
CPMSO	chlorophenylmethyl sulfoxide
CPMSO ₂	chlorophenylmethyl sulfone
CRL	certified reporting limits
CSU	Colorado State University
CSU-GWFlow	Colorado State University Ground-Water Flow Model
CWP	Composite Well Program
DBCP	Dibromochloropropane
11DCE	1,1-dichloroethene
11DCLE	1,1-dichloroethane
12DCE	trans-1,2-dichloroethene
DCPD	dicyclopentadiene
DDT	dichlorodiphenyltrichloroethane
DIMP	diisopropylmethyl phosphonate
DMDS	dimethyldisulfide
DMMP	dimethylmethyl phosphonate
EA	Endangerment Assessment
EA	Environmental Assessment
EPA	U.S. Environmental Protection Agency
ESE	Environmental Science and Engineering, Inc.
°F	degrees Fahrenheit
FCP	First Creek Paleochannel
Fm	Formation
FRICO	Farmer's Reservoir and Irrigation Company
FS	Feasibility Study
ft	feet
ft/day	feet per day
ft/yr	feet per year

ft ³	cubic feet
FY87	Fiscal Year 1987
gal/ft ²	gallons per square foot
GB	Sarin (nerve agent)
GC/MS	gas chromatography/mass spectrometry
gpd/ft	gallons per day per foot
gpd/ft ²	gallons per day per square foot
gpm	gallons per minute
H	Levinstein mustard
HCCPD	hexachlorocyclopentadiene
HGU	Hydrogeologic unit
ICAP	inductively-coupled argon plasma
ICS	Irondale Containment System
ID	inside diameter
in/mo	inches per month
iph	inches per hour
K	hydraulic conductivity
K _d	partition coefficient
LA	Lignite A
LB	Lignite B
LC	Lignite C
LD	Lignite D
lbs/ft ³	pounds per cubic foot
MCL	maximum contaminant level
mg/l	milligrams per liter
mi	miles
MIBK	methylisobutyl ketone
MKE	Morrison-Knudsen Engineers, Inc.
mm	millimeter
mph	miles per hour
msl	mean sea level
NBCS	North Boundary Containment System
NBE	north boundary east
NBTP	North Boundary Treatment Plant
NBW	north boundary west
NWBCS	Northwest Boundary Containment System
NWBP	Northwest Boundary Paleochannel
OAS	Organizations and the State
OD	outside diameter
PI	plasticity index
PID	photoionization detector
PMO-RMA	U.S. Army Program Manager's Office-Rocky Mountain Arsenal Contamination Cleanup
PMSO	Program Manager Staff Office
p,p'-DDE	p,p'-1,1-dichloro-2,2-bis(4-chlorophenyl)-ethylene
p,p'-DDT	p,p'-dichlorodiphenyltrichloroethane
ppm	parts per million

psi	pounds per square inch
PVC	polyvinyl chloride
RCI	Resource Consultants, Inc.
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
RIC	RMA Information Center
RMA	Rocky Mountain Arsenal
RMA-ED	Rocky Mountain Arsenal Environmental Division
SACWSD	South Adams County Water and Sanitation District
SCC	Shell Chemical Company
SCS	Soil Conservation Service
Shell	Shell Chemical Company
SLA	Stapleton International Airport
sq mi	square mile(s)
SW/GW	Surface Water/Ground Water
STP	Sewage Treatment Plant
SVOC	semivolatile organic compounds
SYA	apparent specific yield
t	time
T	transmissivity
111TCE	1,1,1-trichloroethane
112TCE	1,1,2-trichloroethane
TCLEE	tetrachloroethene
TRCLE	trichloroethene
1u	number 1 upper sand
ug/g	micrograms per gram
ug/l	micrograms per liter
ug/m ³	micrograms per cubic meter
USAEHA	U.S. Environmental Hygiene Agency
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
USCS	Unified Soil Classification System
UTM	Universal Transverse Mercator
VC	volcaniclastic interval
VCE	clay-rich stratigraphically equivalent zone to VC
VOC	volatile organic compounds
WES	U.S. Army Corps of Engineers Waterways Experiment Station
WRI	Water Remedial Investigation
WWII	World War Two